

Erosion Potential in Private Forested Watersheds

of Northern California:

A GIS Model

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by

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INTRODUCTION

Timber harvesting is a major land management practice that can affect hillslope stability. Erosion resulting from timber harvesting activities can increase sediment yields 4 to 78 times that of natural forest conditions (Megahan and others, 1978; Bishop and Stevens, 1964; Morrison, 1975). Erosion and sediment production can have long-term impacts on timber site productivity, fish habitat, reservoir storage capacity, and domestic water supplies (Reid and Dunne, 1984; Brown, 1975). With these concerns in mind, the California Department of Forestry and Fire Protection (CDF) contracted with the Department of Conservation's Division of Mines and Geology (DMG) to develop a semi-quantitative method to delineate those forested watersheds which are most susceptible to erosion when hillslopes are disturbed by timber harvest operations.

Intrinsic erosion potential was modeled on private and state-owned commercial timberlands regulated by CDF. The goal was to select the most significant factors controlling erosion that could be delineated consistently over large areas. The effects of forest land management on erosion vary spatially because of differences in climate, geologic materials, vegetative cover, and topography. Therefore all areas are not equally sensitive to a particular forest practice.

A Geographic Information System (GIS) model was developed to prioritize the relative susceptibility of forested watersheds to erosion. A combination of the most significant geomorphic factors which contribute to the driving and resisting forces

controlling landscape denudation -- material strength, slope, and precipitation -- were used to delineate areas most prone to increases in sediment yield.

Most erosion and sedimentation studies heretofore have been limited to the evaluation of local conditions at individual harvest sites or within small hydrologic basins (Sommarstrom and others, 1990; California Department of Water Resources, 1979; Kelsey, 1977). In contrast this study is a regional evaluation of erosion potential based on semi-quantitative analyses.

The purpose of the investigation was to develop a quantitative method for ranking erosion risks based on available geomorphic data and check this system against the experience of field personnel. The study consisted of two parts: 1) development of a GIS based model derived from the physical properties within 530 designated watersheds on private and state-owned commercial timberlands in California. The details of this system are discussed below, and 2) preparation and distribution of a questionnaire requesting information on suspected highly erodible watersheds. The questionnaire was completed by CDF Forest Practice Inspectors; engineering geologists with the DMG Timber Harvesting Plan Review Project; earth science professionals involved with reviewing Timber Harvesting Plans with the Regional Water Quality Control Board (RWQCB); and wildlife biologists with the California Department of Fish and Game (CDFG) involved with evaluating Timber Harvesting Plans. The watersheds identified

from the questionnaire and review of existing data were cross checked with the information developed in the GIS model.

MODEL INPUT

Selection of Geomorphic Variables

The principal factors that have been shown to contribute to erosion in forested terrane are slope steepness, horizontal concavity, high groundwater, cohesionless soils, and weak bedrock (Durgin and others, 1989; Lewis and Rice, 1989; Peters and Litwin, 1983; Campbell, 1975). A total of 23 erosion-contributing variables were explored for potential use in the model during the design of this study. These include soil consolidation, soil permeability, soil depth, soil plasticity, colluvium depth, presence of surficial deposits, geology, vegetation, slope, slope length, slope aspect, land use, rainfall intensity, rainfall duration, seasonality of rainfall, temperature, landscape maturity, dissection density, dissection depth, horizontal curvature, stream inner gorges, ground water table depth, and areas of potential rain-on-snow.

Some factors, such as changes in vegetation, areas and dates of land-use impact, rainfall duration, and rain-on-snow events are difficult to depict in map form due to their temporal variability. Many other of the above factors are not easily depicted in map form at regional scales, such as inner gorge development, stream dissection density and depth, ground water table levels, and horizontal curvature. Because all the areas

in this study were forested, variability in vegetation type was considered to be minimal in terms of providing significant differences in ground coverage. Therefore, the project focuses on regionally consistent and available information over the entire study area. This includes geology (with the susceptibility of each geologic unit to landslide, debris slide, or surface erosion processes), slope steepness, and rainfall intensity (including mean-annual, 12-hour, and 2-hour precipitation).

Approximately 530 watersheds throughout northern California, each about 20,000 hectares, were evaluated in this study. Each watershed contains at least 25% private or state-owned commercial timberland. In each watershed, the physical attributes of slope, precipitation, and lithologic susceptibility to failure, were stratified into low, moderate, and high categories based on the relative contribution of that factor to erosion potential. These data layers were entered as separate digital coverages in an ARC/INFO-based GIS. Rated polygons were area-weighted and additionally combined for each hydrologic basin. Although the relationships between these geomorphic factors no doubt are complex and non-linear, a simple linear additive relationship was used to combine data sets. The highly generalized nature of the input data, the averaging of data over watershed areas, and the lack of established empirical relationships between the data cause the use of complex algorithms to give an improper impression of precision. The use of the additive data combination produces an array of ranked watersheds depicting those basins

which are theoretically most susceptible to accelerated hillslope degradation. Separate erosion-potential maps were generated for three general types of hillslope erosion: landslide, debris slide, and surface erosion.

Study Limitations

Any perturbation to a hillslope system may result in either a large or small erosional response depending on the balance of opposing tendencies preexisting at the site. For example, a hillslope may be steep and may be underlain by easily erodible regolith, but previous evacuation of material from the slope may have left little material available for transport (Figure 1). Similarly, an area of gentle slope may be deeply weathered and have excess material for transport, but land use practices may incur little erosion because the slope is gentle. Thus there is a complex interaction of multiple geomorphic variables which are in a constant state of apparent balance. This concept was summarized by Hack (1960), "A landscape is an open system which is in a steady state of balance with every slope and every form adjusted to every other." The large number of geomorphic variables controlling the evolution of a natural landscape creates a system which is difficult, if not impossible, to evaluate empirically (Leopold and Langbein, 1962; Shreve, 1966, 1975; Smart, 1968, 1972). It is also difficult to predict how close a landscape is to a threshold condition before system disturbance (Bull, 1991).

For these reasons there are no established quantitative relationships between the factors controlling erosion. Although it is difficult to predict the response of a system to a change in land use, many scientists have noted qualitative cause and effect relationships. For instance a disturbance to a slope of moderate steepness on a specific geologic unit will tend to have accelerated erosion. Thus, an essentially qualitative model based largely on the field experience of numerous geologists and other resource specialists has been developed. The design and component input of the model is therefore limited to that of a highly simplistic and qualitative conceptual model.

Data Preparation

Watershed Boundaries

Approximately 530 watersheds, each about 20,000 hectares, were subdivided from preexisting sub-basins defined by the Hydrologic Basin Planning Areas of the RWQCB (1986). Land ownership maps were combined with forest coverage maps compiled by the CDF in order to define areas of private or state ownership with commercial timber. Only watersheds containing 25% or more private or state-owned commercial timberland were selected for this study. Tierra Data Systems provided GIS coverage of the 20,000 hectare watersheds used in this study. Previously existing watershed boundaries were used where possible, causing many watersheds to be administratively defined. Therefore, watershed boundaries are inconsistently represented across the region and

do not always reflect individual hydrologic basins. Such watershed boundaries should not be used for scientific analysis; however, if aggregated into Hydrologic Sub-Basin Areas as defined by the RWQCB (1986), complete hydrologic basins are represented.

Slope

A digital slope map was produced for northern California using a derivative of a 3-arc second raster data set that was developed for the United States by the Army Map Service (now Defense Mapping Agency). The original data set was resampled to 150 X 150m pixel resolution by the U.S. Geological Survey (USGS) in Flagstaff, Arizona. This digital elevation model (DEM) was projected to a Lambert Conformable Conic projection with a central meridian of 119° W longitude. Although this data was carefully edited by the USGS, it retains numerous scanning artifacts contained within the original 3-arc second data.

To evaluate the accuracy of DEM slopes, slopes from selected locations were compared from measurements made in the field, on topographic maps and from digital data with a 150m pixel resolution. These comparisons show that:

1. Field measurements are difficult to correlate accurately to topographic maps due to the complex microtopography in the field.

2. Although a comparison of digital slope measurements with topographic slopes shows a discrepancy at individual sites, a consistent relationship exists between digital slopes and topographic slopes when digital slopes are averaged over an entire drainage basin.
3. Digital slopes from random locations are up to 7% to 10% lower on average than topographic slopes (Figure 3).
4. Slopes are calculated in eight directions surrounding a central elevation. The steepest slope is assigned to a 150 x 150m pixel. This tie-limited spatial resolution of the digital slope calculations cause slopes less than about 300m in length to be measured inaccurately (Figure 4).

Geology

Qualitative evaluations of geologic material strength were developed from personal interviews with 21 professional geologists who have extensive experience with erosion in timber harvest areas in northern California (Table 1). The geologists were asked to classify the geologic units with which they were most familiar in terms of susceptibility to 1) landsliding, 2) debris sliding, and 3) surface erosion. Relative ratings of low, moderate, and high were assigned to each geologic unit (Table 2). To insure regional validity for the erosion values, geologists were asked to consider erosion responses on equivalent slopes, and to use their statewide knowledge of erosion susceptible

lithologies when drawing comparisons for their specific area of expertise.

The geology data layer was digitized for generating the digital material-strength field for erosion analyses using a vector scan of scribed linework of the 1:750,000 scale geologic map of the State of California (Jennings, 1977). Line editing and polygon labeling were performed by USGS and DMG personnel at the USGS Western Regional Center, Menlo Park, California. Co-registered hydrologic features (coastlines, lake shorelines, and river channels) were also scanned to enable accurate co-registration with the DEM.

Precipitation

The precipitation data were manually digitized by DMG personnel from 1:1,000,000 scale blue line maps prepared for the CDF (1984). Digitized precipitation maps include, 1) mean annual precipitation (Rantz, 1969), 2) 12-hour intensity with a 50 year recurrence probability, and 3) 2-hour intensity with a 50 year recurrence probability. The location of isohyetal lines is highly generalized: rainfall data in the study area were extrapolated from only 150 rain gages -- about one for every 100,000sq-km. In addition, few of these gages are in mountainous areas, so orographic effects have been estimated using manual techniques (U.S. National Weather Service, oral communication, 1993).

Analysis

To preserve the integrity of the DEM slope data, the Lambert Conic Conformable projection (119 central meridian) of the DEM data was adopted as the map projection for this project. The vector data layers (geology, precipitation, and watershed boundaries) were reprojected to this coordinate system. The Lambert Conic Conformable projection approximates the Albers Equal Area projection and therefore is well suited for applications of regional spatial analysis. The vector data layers (geology and precipitation) were rasterized to the level of precision of the digital elevation raster layer (150 X 150m pixels). To estimate the relative erosion potential of each pixel area, the raster data layers were added together within each pixel area according to the ranking scheme summarized in Tables 2 and 3. Separate analyses were calculated for each of the three major slope erosion categories - landslides, debris slide, and surface erosion. For each of these analyses the pixel values within each watershed were summed and averaged to calculate a rating value for each watershed. The results of these three erosion ratings were then added to estimate the total erosion potential for each watershed (Table 4). The highest possible theoretical rating is 9 where 100% of the watershed contains high geology, precipitation, and slope ratings. The highest rated watershed in our analyses is 7, and the average relative erosion rating is 4.

Systematic visual inspection of a digital overlay of stream channels, derived from a digital scan of hydrologic features co-registered with the geology scan and the 150 X 150m pixel DEM, indicates that the general locational precision of the various data layers falls within $\pm 300\text{m}$ or 2 DEM pixels ($\pm 0.6\text{mm}$ at 1:500,000 scale).

MODEL OUTPUT

Sources of hillslope sediment include landslides, debris slides, and surface erosion. Because the physical controls on failure for these three potential source types differ, they were modeled independently.

Landslides

Landslides modeled in this study include mass failures that have planes of failure that are relatively deep, generally greater than 3m, and have a fairly low width to depth ratio. The types of failures included in the landslide model are rotational and translational landslides (rock slumps, earth slumps, rock block slides, and earth block slides) and earth flows (Varnes, 1978). Many scientists have attempted to correlate deep-seated mass movement with the amount of precipitation; however, these studies show that the relationship is complex (Iverson and Major, 1987; Swanson and Swanson, 1977; Swanson, 1981; Campbell, 1975). Although the complex movement of subsurface water flow has thwarted attempts to use rainfall as a systematic predictor of

landslide movement, most geomorphologists agree that the occurrence of deep-seated hillslope failure is related to seasonal precipitation (Brunsden, 1993; Jahns, 1969; Keefer and Johnson, 1983; Swanson and Swanston, 1977; Swanston, 1981).

The regional nature of this study, combined with the lack of empirical relationships between rainfall and landslide movement requires the use of a highly generalized rainfall distribution to model spatial patterns of relative ground saturation. Mean annual precipitation was chosen to provide a pattern of general rainfall for estimation of relative landslide potential. Low, moderate, and high ratings have been assigned to precipitation values to reflect resultant, and highly generalized landslide susceptibility categories (Table 3).

Likewise, the relationship between slope gradient and mass wasting processes is highly generalized due to the complexities of geologic, climatic, and land-use factors. For purposes of this model, steeper slopes are assumed to have a greater driving force with slopes from 10% to 30% being assigned a low value, 30% to 50% moderate, and steeper than 50% as high.

Geologic structure and lithology are significant factors predisposing certain terrane to mass movement. This trend is observed on geologic maps in California that show the majority of mapped landslides to be concentrated on a few geologic units. In some regions the overriding influence of lithology has created the basis of landslide classification (Takada, 1964). The area of highest landslide propensity in the study area occurs in the

central and eastern belts of the Franciscan Complex. Here melange and highly sheared and faulted sedimentary and metamorphosed sedimentary rock dominate. The mineralogic composition of the rocks causes them to be conducive to weathering and alteration to clay-rich material, becoming subject to extensive landslide and earthflow movement (Kelsey, 1977). In fact, landsliding may be the dominant erosion process in the northern Coast Ranges.

Debris Slides

Debris slides modeled in this study include mass failures that have surfaces of failure that are relatively shallow, generally fewer than 3m, and have a fairly high width to depth ratio. The types of failures included in the debris slide model are rock, debris, earth falls and toples, debris slides, and debris flows (Varnes, 1978). Other terms used include debris torrents, mudflows, debris avalanches, soil flows, and soil slips (Cannon and Ellen, 1985; Campbell, 1975; Keefer and Johnson, 1983; Wieczorek, 1987; Ellen and others, 1993; Caine, 1980; Wentworth, 1943). Debris slides commonly occur where thin colluvial deposits blanket less permeable bedrock or soil material (O'Loughlin, 1972; Swanston, 1974; O'Loughlin and Pearce, 1976; Ellen and others, 1993). Once saturated, these deposits exceed the resisting forces and fail. Many studies have documented the predictive relationship between rainfall intensity and shallow debris flows (Campbell, 1975; Cannon and Ellen, 1985; Caine, 1980; Wieczorek, 1987). These studies note that antecedent

water storage followed by a high intensity storm systematically triggers debris flows (Canon and Ellen, 1985).

Campbell (1975) and Wieczorek and Sarmiento (1983) indicate that 10 to 15 inches of antecedent seasonal rainfall is sufficient to set the stage for debris slides. Once field capacity of the soil mantle has occurred, a high intensity storm with extreme 1 to 24-hour precipitation can cause saturation and failure (Figure 2). For a 12-hour duration storm, a failure threshold has been shown to occur at a rainfall intensity of 0.2 to 0.4 inches/hour (Cannon and Ellen, 1985) and 0.25 inches/hour (Campbell, 1975; Caine, 1980). For this study rainfall intensities below 0.2 inches/hour were considered to be low and above 0.4 inches/hour were designated high. Isohyetal locations were obtained from a rainfall intensity map of California with a 12-hour duration and 50-year recurrence probability (CDF, 1984).

Many researchers have attempted to correlate debris slide occurrence with hillslope gradient. Shallow mass wasting typically occurs on steeper slopes than do deep-seated slides, with debris slides commonly occurring on slopes between 40% and 100% (Campbell, 1975; Sidle and others 1985; Durgin and others, 1989; Corbett and Rice, 1966; Rice and Foggin, 1971; Kesseli, 1943; Johnson and Sitar, 1990).

In northern and central California, low-cohesion material formed from weathered granite or sandstone bedrock shows the highest tendency for debris slide failure. In the Coast Ranges, the Redwood Creek and South Fork Mountain schists of the

Franciscan terrane are highly susceptible to debris slides; in the Sierra Nevada and Klamath province, granitic plutons are commonly susceptible. However, mass wasting is limited to areas where hillslope detritus is available; steep slopes (over 100%) may be covered by little colluvium (Campbell, 1975).

Surface Erosion

In this study surface erosion includes sheetwash, ravelling, rilling, and gullyng. An undisturbed forest in its natural pristine condition usually yields very little surface runoff (Dissmeyer and Foster, 1980). The forest ground cover (litter, logs, and rock) protects the soil from raindrop impact and surface runoff, creating infiltration rates which usually exceed rainfall intensity. However, land use impact resulting from mechanical site disturbance, (including road building, tractor yarding, site preparation, and fire) destroys vegetative cover, locally compacts the soil and exposes bare soil to the erosive energy of rainfall and runoff.

A few attempts have been made to quantitatively model approximations of surface erosion controlling factors in forested regions (Dissmeyer and Foster, 1980; California Soil Survey Committee, 1989). U. S. Department of Agriculture (USDA) (1978) identified six factors contributing to surface erosion in agricultural fields. However, the empirically derived relationships known as the Universal Soil Loss Equation (USLE) shows a poor correlation to sediment yield on forested hillslopes

(Dodge and others, 1976). Part of this disparity results from the derivation of the USLE on gently sloping, finely textured agricultural fields, whereas forested landscapes are topographically, botanically, and lithologically diverse and thus difficult to model over large areas.

Three factors were chosen to approximate regional susceptibility of forested hillslopes to surface erosion: a 2-hour high intensity rainfall storm with a 50 year recurrence probability, slope, and lithologic potential for surface erosion. Soil loss per unit area generally increases in proportion to a power of hillslope gradient. In this study, surface erosion potential was rated low on 10% to 30% slopes, moderate on 30% to 50% slopes, and high on greater than 50% slopes.

Spatial Relations

Areas of steepest slope include the Klamath physiographic province and the deep canyons draining the west flank of the Sierra Nevada.

Mean annual precipitation is highest in northwestern California north of Eureka. Annual rainfall is moderate in the Coast Ranges north of Santa Rosa, in the Sierra Nevada Mountains, and in the Klamath province. Two-hour and 12-hour precipitation intensities show a generally similar distribution to mean annual precipitation with particularly high intensity rainfall over Arcata, Mount Shasta, and the Santa Cruz Mountains.

The general lithologic patterns in California roughly coincide with geomorphic provinces (Jenkins, 1938) and with tectonostratigraphic terranes (Auboin and others, 1980; Irwin, 1966) (Figure 5). These include 1) the coastal Franciscan Complex, composed chiefly of Mesozoic and Cenozoic sedimentary and metavolcanic rocks which are highly sheared and deformed, 2) the Klamath crystalline basement complex consisting of highly metamorphosed Mesozoic and Paleozoic rock intruded by Mesozoic plutons, 3) the Cascade and Modoc provinces comprised of late Cenozoic and Quaternary volcanics, 4) and the Sierra Nevada Mountains cored by Mesozoic granite and granodiorite intruding metamorphosed Mesozoic and Paleozoic igneous and sedimentary rock pendants of the foothill region.

Erosion Potential

Watershed erosion ratings are high where one data layer is high and two out of three are either high or moderate. Therefore, although the Klamath province and the deep canyons of the Sierra Nevada are lithologically resistant, high precipitation and slope values give these areas high erosion ratings.

Of course, estimates of erosion potential generated for each pixel show greater geographic detail than estimates averaged over 20,000 hectare watersheds. This apparent detail, however, is somewhat misleading in that the detailed breaks between data units cause sharp contrasts which are not representative of actual field conditions. The generalized nature of individual

data layers, combined with the uncertainty of geomorphic response furthermore causes imprecision of erosion values at specific locations. Only when erosion values are averaged over drainage basins do they accurately reflect the erosion potential.

Landslide Potential

The area of highest landslide potential exists in the Coast Range province, specifically in the eastern and central belts of the Franciscan terrane north of Clear Lake (Figures 5 and 6). Here, melange, clay-rich soil, and moderately steep slopes combined with moderate to high precipitation (100 to 250cm/yr) create unstable hillslopes. Landslide potential is generally low in the Sierra Nevada, with a few landslide-prone watersheds on the more clay-rich weathered metamorphosed Mesozoic and Paleozoic roof-pendant rock of the northern foothill region. In the Klamath province, landslide potential is highly variable, ranging from low to high with the highest potential occurring on the western side of the province where serpentized ultramafic rock, steep slopes, and high precipitation create unstable hillslope conditions. Landslide potential in the Modoc and Cascade provinces is low, with only a few localized problem sites.

Debris Slide Potential

Debris slide potential is modeled as low to moderate in the Coast Ranges (low from the Santa Cruz Mountains to Santa Rosa, and moderate north of Santa Rosa) (Figure 7). In the Klamath

province, debris slide potential is highly variable, ranging from low to high in a scattered pattern, while in the Cascade and Modoc plateaus debris slide potential is low. In the Sierra Nevada Mountains the potential is generally low with a few scattered watersheds having a moderate potential.

Surface Erosion Potential

Surface erosion ratings are low to moderate in the Coast Ranges, low to moderate in the Klamath province, and low in the Cascade, Modoc Plateau, and Sierra Nevada Mountains (Figure 8).

Total Erosion Potential

Total erosion potential combines landslide, debris slide, and surface erosion ratings within each watershed (Figure 9). The geographic distribution of relative erosion susceptibility shows a high potential in the northern coast ranges, moderate in the Klamath province, moderate to low in the Sierra Nevada Mountains, and low in the Cascade and Modoc Plateau physiographic provinces. This pattern of general erosion susceptibility is similar to that of the modeled landslide potential (Figure 6).

DISCUSSION

How well these modeled watershed values represent actual erosion potential is important if the watershed-rating maps are to be used for planning purposes. By understanding the limitations and uncertainties of the data used in this analysis,

a more realistic use of the model can be facilitated. This will also aid in evaluating the accuracy of the model.

Four limitations contribute to the uncertainty of this analysis. First, geomorphic processes range widely, even in similar physiographic settings. In northern California, the inner-gorges of steeply sloping streams contribute significantly to total sediment yield within local watersheds (De la Fuente and Haessig, in review). Here steep stream canyon walls are cut into the toes of broad hillslopes. The undermined colluvium at the toe of the slope creates a continual cascade of weathered hillslope material into the streams. The break in hillslope gradient in these canyons suggests that the stream and hillslope systems are not in equilibrium, and that there has been a change in the rate of stream degradation at some point in the recent past. This allows a reservoir of hillslope material to be available for erosion.

Sediment transport from hillslopes to streams in many areas of the Sierra Nevada, however, operates quite differently. Here stream gorges are often bedrock walled and little or no colluvium is available for downslope transport. The process of grussification of granitic rock requires moisture to be retained at depth for prolonged periods of time. On steep slopes weathered material is rapidly removed, and a self-enhancing feedback loop occurs where bare rock does not retain moisture long enough to form crystalline detritus or gruss. Thus, in some of the deep, steep-sided gorges of the Sierra Nevada, little colluvium exists

and, unlike the Coast Ranges, little sediment is available for stream transport. Slope steepness, then, by itself may not be a reliable indicator of erosion potential if no colluvial material is available for erosion.

Second, many workers have attempted to relate rates of sediment transport to landscape variables, yet understanding the relationship between geomorphic variables is incomplete. For this analysis a simple linear relationship between these variabilities was used. In reality these relationships are highly complex and involve the interactions of many variables not utilized in this analysis. Furthermore, the highly generalized nature of the input data, combined with the lack of empirically derived relationships between data sets, creates large uncertainties in the accuracy of the model. To structure the analysis in such a way as to assume precision between data sets would be to misrepresent the large uncertainties involved in the data relationships. It is therefore appropriate, and has been the consistent intent of this study, to keep all aspects of the model as simple as possible including the analysis, as it is based largely on the qualitative observations of landscape processes.

Third, despite the unlimited number of factors affecting rates of hillslope erosion, this model uses only three factors: slope, precipitation, and lithology. Although they are generally the most important under natural conditions, these three factors account for only a part of the variability in erosion potential.

Fourth, the data input into this analysis is highly generalized. The geologic units used at the 1:750,000 scale are amalgamations of several map units from larger scale maps. These units, in turn, commonly include a variety of lithologic types. The slope estimates are likewise inaccurate at less than a 300m grid. Precipitation data is furthermore derived from one gaging station every 100,000sq-km.

Developing ways to quantify, map, and integrate the variables that influence rates of erosion is a major challenge facing natural resource scientists. Although this model of relative erosion susceptibility is highly qualitative, it attempts to synthesize the physical attributes at a regional scale in California. To appraise the reliability of the model for identifying problem watersheds, three sources of data are examined: questionnaires inviting identification of known areas of erosion, published information on specific watershed studies, and suspended sediment yield data from large drainages.

Natural resource specialists working in timber-harvest-related activities were asked to identify watersheds that had potentially high rates of erosion (Table 5). Agencies responding to this questionnaire included the CDF, the RWQCB, the State Water Resources Control Board (SWRCB), DMG, and DFG. Nineteen responses were received identifying 121 watersheds distributed throughout most of the study area. To augment these observations, 32 studies of erosion in northern and central California were reviewed. These data are summarized in Figure 10 and Table 5.

The observed problem watersheds generally correspond with modeled watersheds having moderate to high ratings. Furthermore, the problem watersheds specifically correspond with modeled landslide potential rather than debris slide or surface erosion potential. In contrast, however, many of the erodible watersheds selected by modeling are not recognized as susceptible to accelerated erosion by field observations. Also, about 20% of those considered problem watersheds are in areas of extremely low ratings based on the model. Several reasons could account for this discrepancy. First, field observations may be incomplete or inconsistent. Second, land use impacts are not part of the intrinsic erosion potential model but may well be the primary factor creating observable erosion problems. Third, additional important factors such as inner gorge development, glacial history, and topographic maturity could add accuracy and detail to the resultant analysis.

Suspended sediment data support the general trends observed between the geomorphic provinces found in the erosion model. These data indicate that the Coast Range province in northwestern California is the most rapidly eroding area in the conterminous United States (Holeman, 1968; Curtis and others, 1973). These especially high erosion rates have been attributed to the lithologically unstable Franciscan terrane, geologically recent tectonism, high and distinctly seasonal precipitation, and major land use disruption. In contrast, the crystalline rock of the Klamath province is generally characterized by substantially lower mean annual suspended sediment yields than the Coast Ranges

(Jones and others, 1972; De la Fuente and Haessig, in review). Moreover in the Sierra Nevada Mountains, suspended sediment yields are 30 times lower than averages from watersheds in the Coast Ranges (Nolan and Hill, 1991).

ADDITIONAL WORK

Additional data layers could enhance the erodible watershed inventory model by including information on land use history, soil properties, transient snow zone boundaries, geomorphic limits of inner gorge development, and areas of Pleistocene glaciation. The applicability of these data layers is described below.

Land Use

Land use activities can result in substantial increases in soil erosion. Clear cut timber harvesting and roading resulted in sediment yields 17 times higher than those in comparable unharvested basins in the Redwood Creek area of northwestern California (Janda, 1978). Although activities that directly increase erosion rates have been substantially reduced by Forest Practice Act regulations, the long term effects of past activities undoubtedly continue to influence sediment yields.

Digital land use data have been developed for California by the EROS Data Center, National Mapping Division, USGS and the University of Nebraska, Lincoln, using Advanced Very High Resolution Radiometry Imagery (AVHRRP). Older land use files have

also been published by the EROS Data Center as Land Use-Land Cover maps. These files could be used to identify where temporal changes in land use activities have occurred.

Soil Properties

The availability of weathered material is a critical component to erosion-potential mapping. The depth and grain size distribution of the regolith, however, can be difficult to measure and varies widely even on homogeneous rock (Wahraftig, 1965). The USDA, Soil Conservation Service, has compiled digital coverage of soils for the state (STATSGO). Although highly generalized, it could be a useful data layer to supplement the lithologic component. Delineation of low cohesion soils may be useful for modeling surface erosion and debris slide potential, and high cohesion soils may provide further accuracy for modeling landslide potential. These models could then be compared to and adjusted to those defined by the geologic data. In addition, soil depth might be used for defining areas of hillslope sediment availability.

Transient Snow Zone

Within a given drainage basin, large storm events can mobilize material equivalent to many times the mean annual sediment yield (Janda and Nolan, 1979). In northern California, extreme runoff events typically result from high intensity tropical storms melting snow pack. It may be possible to

delineate those areas where this phenomenon, known as the rain-on-snow-zone, could impact drainage basins. By using the methodology developed by the State of Washington (Green and others, 1993), a model could be developed that would define the boundaries of those areas most susceptible to rain-on-snow events.

Inner Gorge

Steep inner gorges contribute significantly to total sediment yield in many streams (De la Fuente and Haessig, in review). Areas containing these landform features could be outlined and added as another data factor.

Review of published literature, interviews with geologists and geomorphologists, aerial photographic interpretation, and field mapping will be required to identify boundaries separating regions where inner gorges are common from those areas where they are rare. Because of the complex nature of the tectonic processes that result in rapid watercourse base level changes, separating these areas will be time consuming and controversial.

Pleistocene Glaciation

Glacial scour has removed weathered hillslope material from areas of high elevation in the Sierra Nevada, Klamath, and Cascade physiographic provinces. Delineating areas of glaciation would further define watersheds with limited availability of weathered material.

Watershed-Scaled Analysis

A GIS-based model of erosion potential could be developed for a relatively small watershed to attempt to quantify erosion controlling factors. Detailed geomorphic mapping at a scale of 1:24,000 by DMG is in progress for three watersheds in northern California. A geology and geomorphology data layer combined with digital elevation data or a digital terrane model developed from aerial photographs could be used in conjunction with sediment yield data to define more detailed algorithms for sediment yield modeling.

Conclusion

The understanding of the relationship between geomorphic variables is complex and incomplete. As research on sediment yield, sediment transport, and geomorphology advances, the understanding of the relative significance of individual factors controlling erosion will be improved. The results of current and future research, in conjunction with the suggested further work, can be used to improve the quality of the erodible watershed inventory model.

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Figure 1

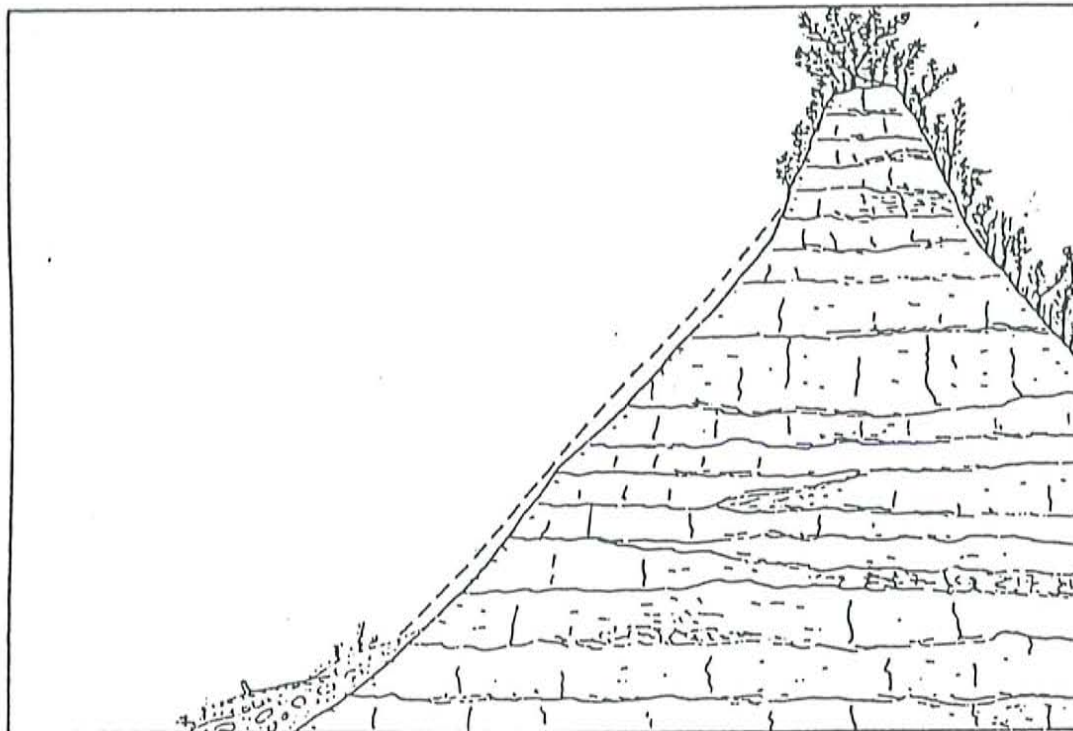


Figure 2

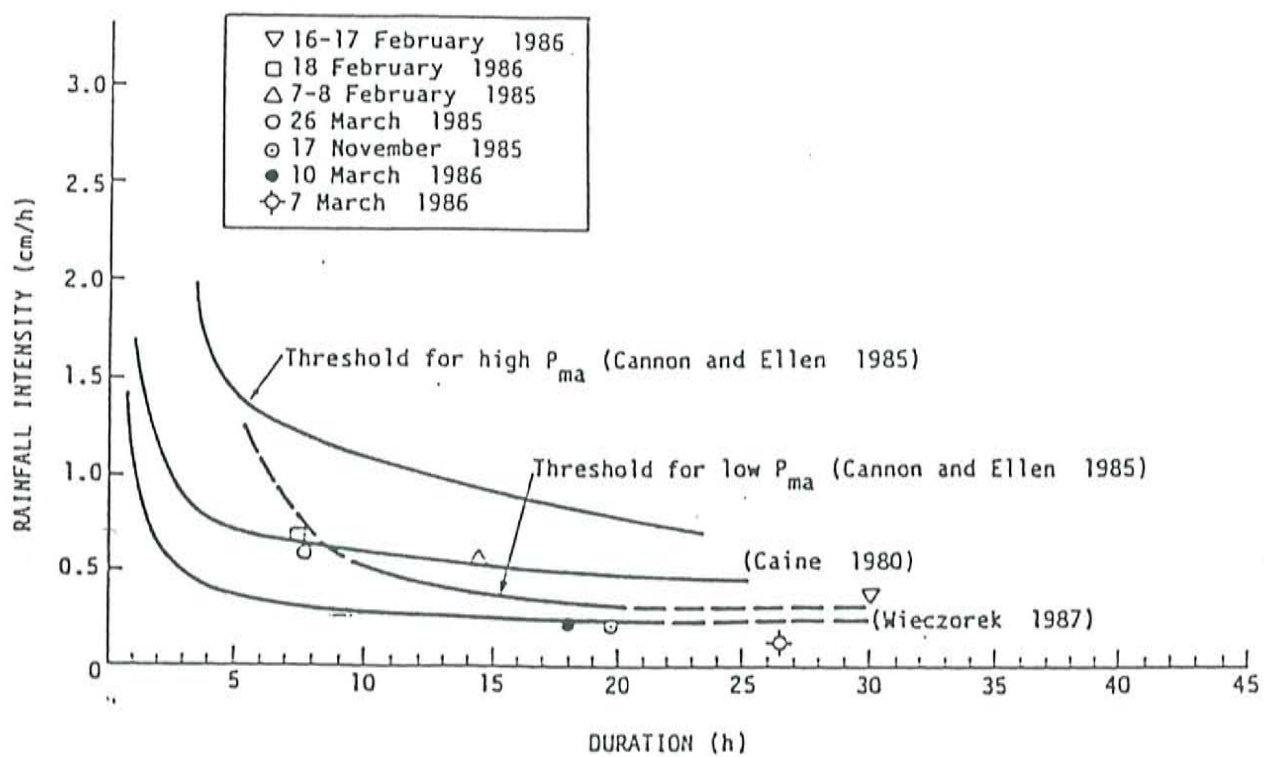


Figure 3

Slope Calculation

$$\text{Slope} = \text{Max} (X_0 - X_{12}, X_{21}, X_{23}, X_{32}) / 150$$

$$\text{or } (X_0 - X_{11}, X_{13}, X_{31}, X_{33}) / 211$$

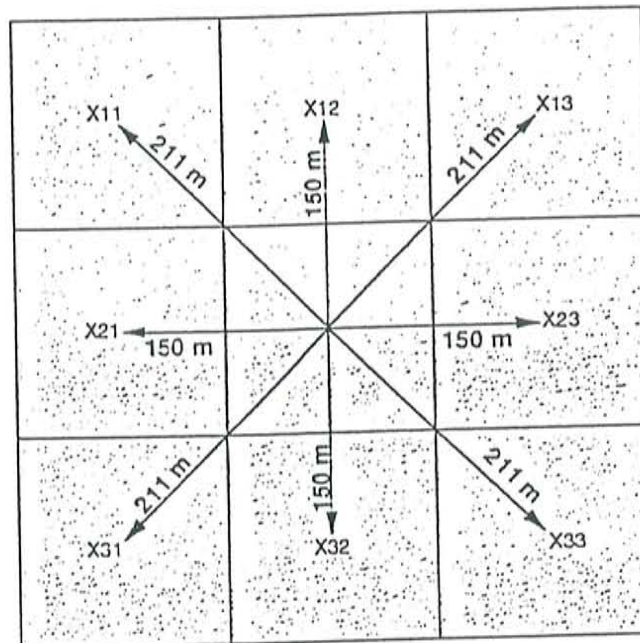


Figure 4

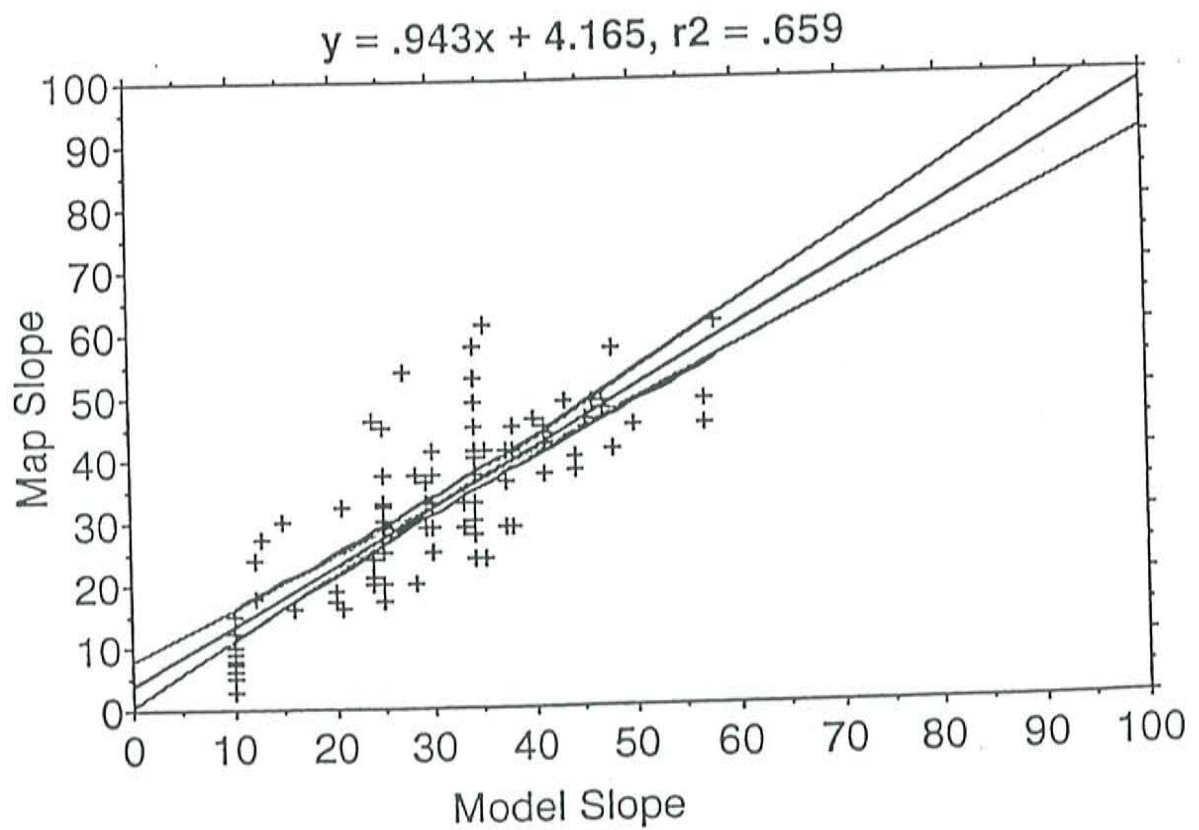


Figure 5
Lithotectonic Belts of Northern and Central California

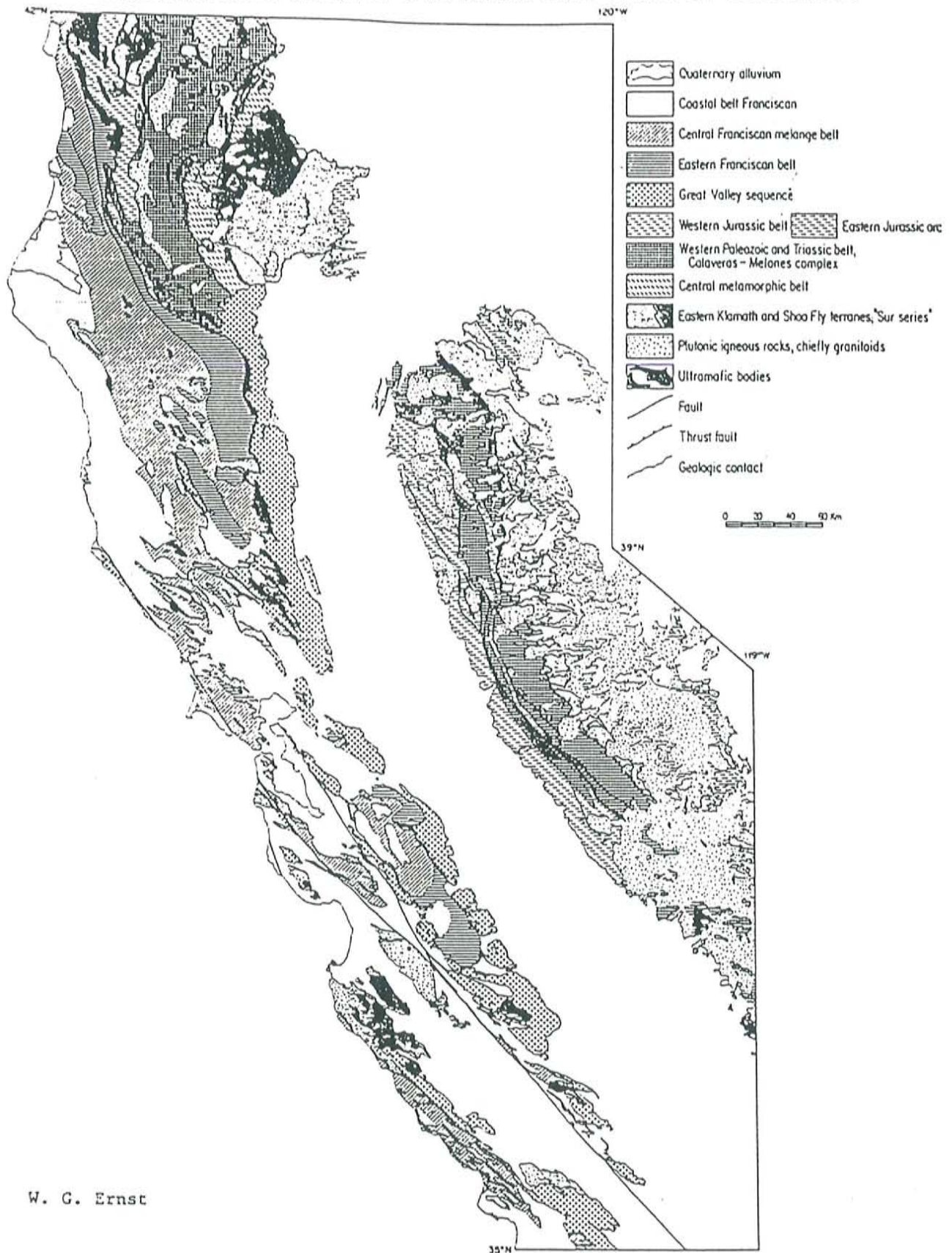


Figure 6

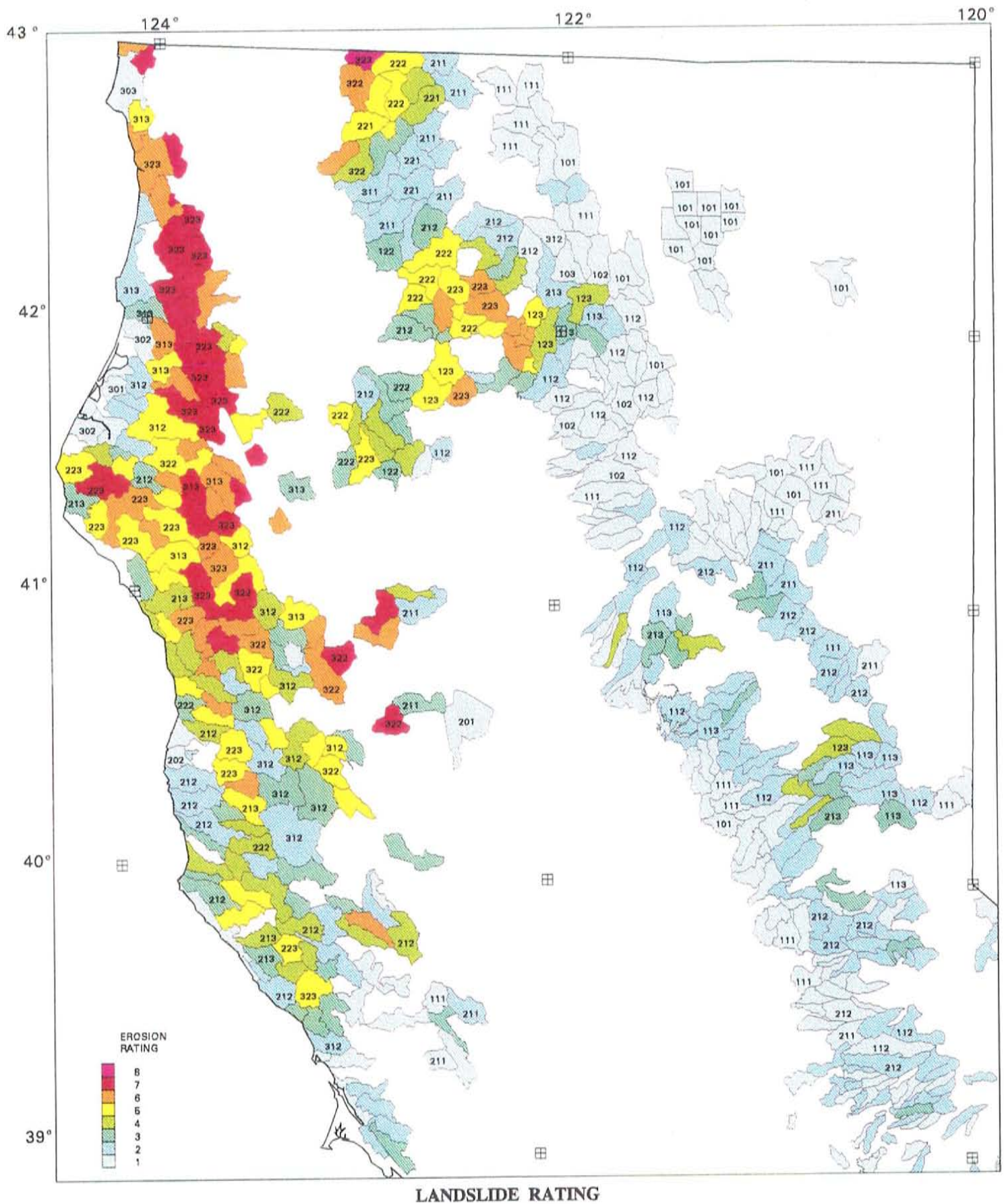


Figure 7

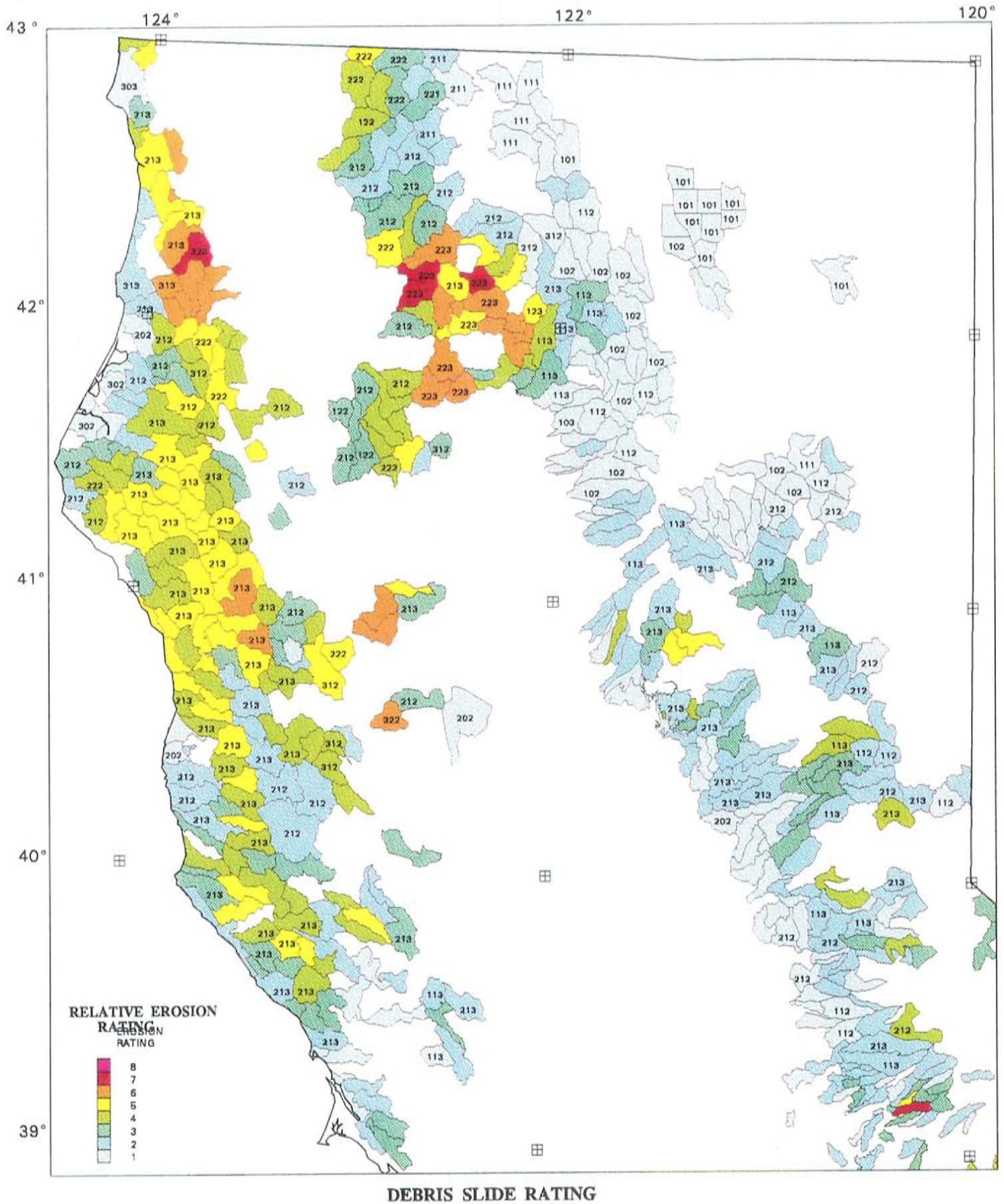


Figure 8

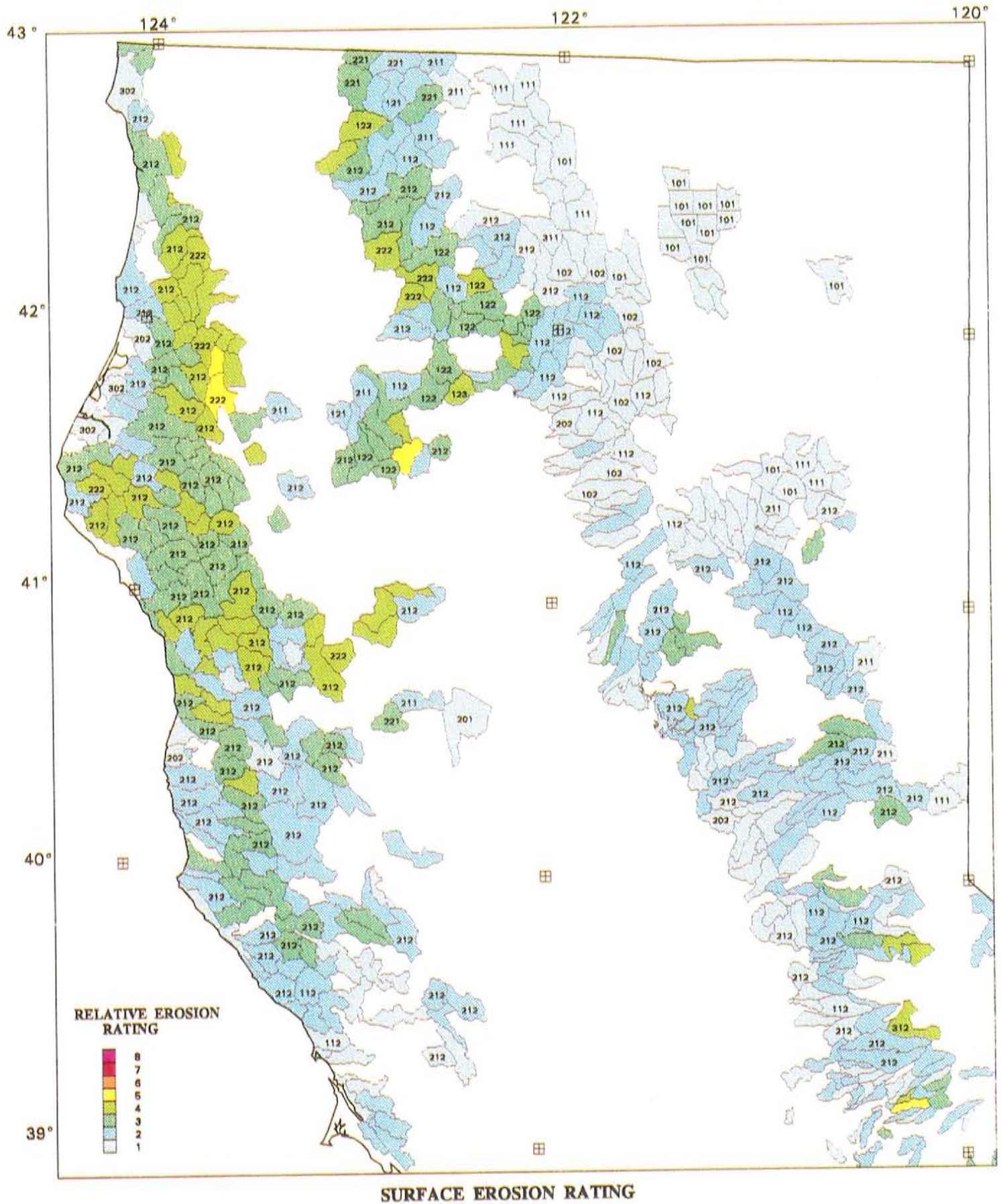


Figure 9

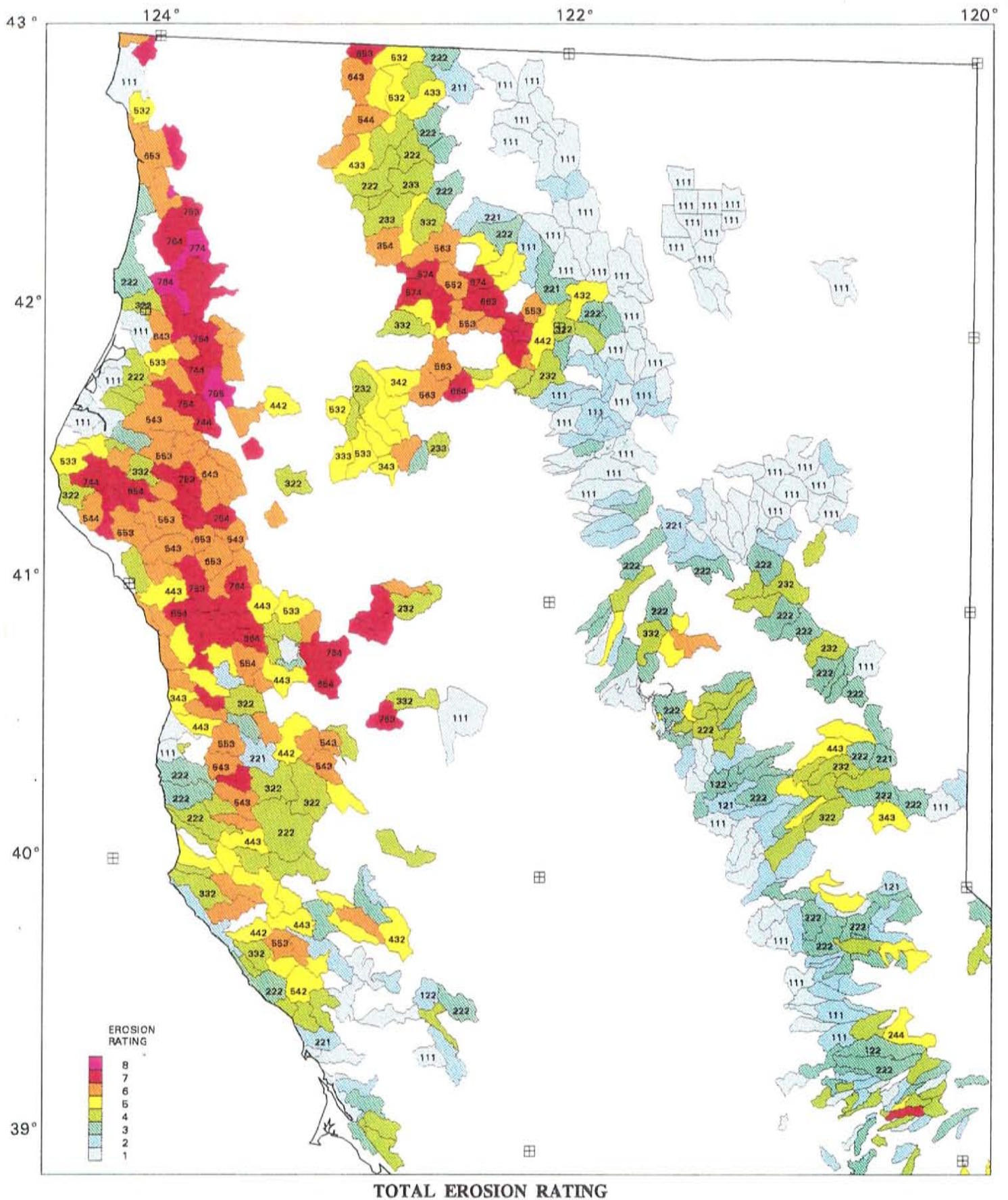


Figure 10

Observed Problem Watersheds

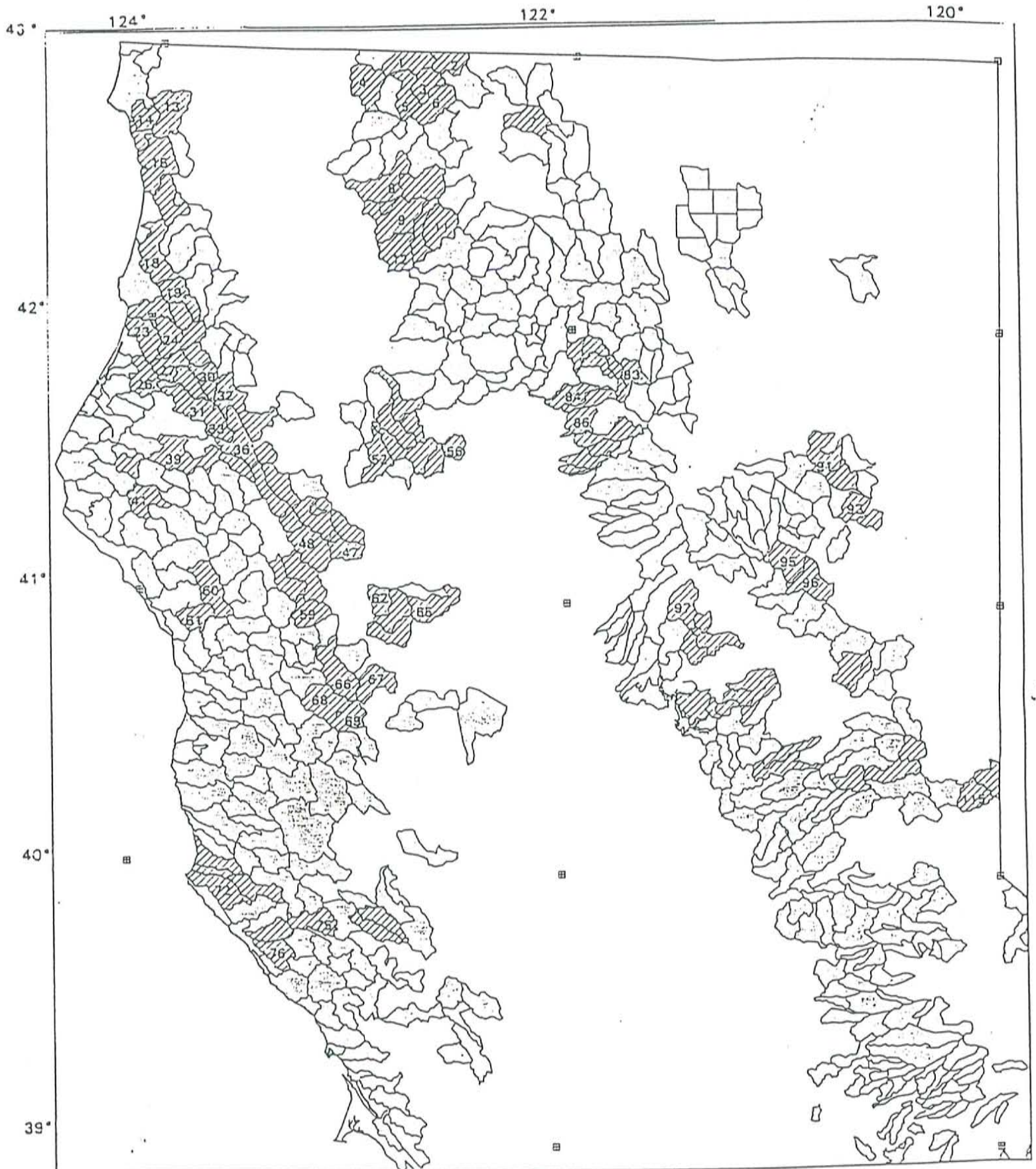


FIGURE CAPTIONS

- Figure 1 Sketch of hillslope stripped of colluvium.
- Figure 2 Published rainfall intensity-duration thresholds for debris-flow failures (From Johnson and Sitar, 1990).
- Figure 3 Schematic diagram showing DEM slope calculations. The value of the medial pixel is derived from the highest of eight adjacent slope calculations.
- Figure 4 Graph of topographic slope versus digitally modeled slope.
- Figure 5 Lithotectonic belts of Northern and Central California.
- Figure 6 Colors represent the relative landslide susceptibility of watersheds. Numbers within watersheds refer to the individual factor values comprising the rating including geology, slope, and precipitation consecutively.
- Figure 7 Colors represent the relative debris-slide susceptibility of watersheds. Numbers within watersheds refer to the individual factor values comprising the rating including geology, slope, and precipitation consecutively.
- Figure 8 Colors represent the surface erosion susceptibility of watersheds. Numbers within watersheds refer to the individual factor values comprising the rating including geology, slope, and precipitation.
- Figure 9 Total erosion susceptibility ratings. Numbers within watersheds refer to landslide, debris slide, and surface erosion ratings consecutively.
- Figure 10 Distribution of watersheds with observed erosion problems. (Refer to Table 4 for detailed information.)

Table 1

List of Contributors to the Geologic Unit Ratings

<u>Scientists</u>	<u>Agency</u>	<u>Location</u>
Don Haskins	NFS	Redding
Gerry de Graff	NFS	Fresno
Gordon Keller	NFS	Quincy
Mark Smith	NFS	Eureka
Tom Lisle	NFS	Arcata
Juan de la Fuente	NFS	Yreka
Bob Faust	NFS	Willows
John Chatoian	NFS	San Francisco
Oscar Huber	DMG	Fortuna
Julie Bawcom	DMG	Ukiah
John Schlosser	DMG	Redding
Dave Wagner	DMG	Sacramento
Tom Spittler	DMG	Santa Rosa
Porter Irwin	USGS	Menlo Park
Dave Harwood	USGS	Menlo Park
Tom Schott	SCS	Ukiah
Bob Currey	UCSC	Santa Cruz
Mark Foxx	Private	Santa Cruz
Hans Neilson	Private	Santa Cruz
Danny Hagens	Private	Arcata

Table 2

Geologic Rating Table

Rating:
 ls - landslide
 df - debris flow
 se - surface erosion
 1 - low
 2 - moderate
 3 - high

Scale: 1:750,000	Scale: 1:250,000
<p>Qs - Extensive marine and nonmarine sand deposits, generally near the coast or desert playas.</p> <p>Rating: ls - 1 df - 3 se - 3</p>	<p><u>Weed</u> Qs - Dune and beach sand.</p> <p><u>Alturas</u> Ql - Quaternary lake deposits.</p> <p><u>Santa Rosa</u> Qs - Dune and beach sand.</p>
<p>Q - Alluvium, lake, playa, and terrace deposits; unconsolidated and semi-consolidated. Mostly nonmarine, but includes marine deposits near the coast.</p> <p>Rating: ls - 3 df - 3 se - 3</p>	<p><u>Weed</u> Q - Alluvium Qs - Dune and beach sand Ql - Lake deposits Qt - Terrace deposits Qmt - Marine terrace deposits Qc - Fluvial deposits (Gravel, sand, and silt) Qby - blue sandstone and clay (Marine and continental) - Battery Formation</p> <p><u>Redding</u> Qal - Alluvium Qm - Pleistocene marine and marine terrace deposits Qc - Pleistocene nonmarine Qt - Quaternary nonmarine terrace deposits</p> <p><u>Ukiah</u> Qm - Pleistocene marine and marine terrace deposits Qf - Fan deposits</p> <p><u>Alturas</u> Ql - Quaternary lake deposits Qc - Pleistocene nonmarine Qal - Alluvium</p> <p><u>Susanville</u> Ql - Quaternary lake deposits Qal - Alluvium Qt - Quaternary non-marine terrace deposits</p> <p><u>Chico</u> Q - Alluvium Ql - Lake deposits Qf - Fan deposits Ps - Pliocene nonmarine sedimentary rocks (Fluvial and lacustrine shale, sandstone, and ash) Qt - Terrace deposits</p> <p><u>Santa Rosa</u> Qt - Terrace deposits</p> <p><u>Santa Cruz</u> Qm - Pleistocene marine and marine terrace deposits</p> <p><u>San Francisco and San Jose</u> Qt - Terrace deposits</p>
<p>Qg - Glacial till and moraines. Found at high elevations mostly in the Sierra Nevada and Klamath Mountains.</p> <p>Rating: ls - 2 df - 2 se - 2</p>	<p><u>Weed</u> Qg - Glacial deposits (Outwash & morainal)</p> <p><u>Redding</u> Qg - Glacial deposits</p> <p><u>Chico</u> Qg - Glacial deposits</p> <p><u>Sacramento</u> Qg - Glacial deposits</p>

Table 2

Scale: 1:750,000	Scale: 1:250,000
<p>Qls - Selected large landslides, such as Blackhawk Slide on north side of San Bernardino Mountains; early to late Quaternary.</p> <p>Rating: ls - 3 df - 2 se - 2</p>	<p><u>Weed</u> Qls - Dune and beach sand</p> <p><u>Chico</u> Qls - Landslide deposits.</p> <p><u>Santa Rosa</u> Qls - Landslide deposits.</p> <p><u>San Francisco and San Jose</u> Qls - Landslide deposits.</p>
<p>Qrv - Recent (Holocene) volcanic flow rocks; minor pyroclastic deposits.</p> <p>Rating: ls - 1 df - 1 se - 1</p>	<p><u>Weed</u> qv^a - Andesite - Volcanic rocks qv^b - Basalt - Volcanic rocks qv^d - Dacite - Volcanic rocks</p> <p><u>Alturas</u> mv^b - Basalt - Miocene volcanic tv^p - Pyroclastic rocks - Tertiary volcanic pv^a - Andesite - Pliocene volcanic</p>
<p>Qrv^p - Recent (Holocene) pyroclastic and volcanic mudflow deposits.</p> <p>Rating: ls - 1 df - 1 se - 2</p>	
<p>Qv - Quaternary volcanic flow rocks; minor pyroclastic deposits.</p> <p>Rating: ls - 1 df - 1 se - 1</p>	<p><u>Weed</u> pv^b - Basalt - Volcanic rocks</p> <p><u>Redding</u> qpv^b - Basalt - Pleistocene volcanic</p> <p><u>Alturas</u> qpv^b - Basalt - Pleistocene volcanic mv^b - Basalt - Miocene volcanic tv^a - Andesite - Tertiary volcanic tv^p - Pyroclastic rocks - Tertiary volcanic pv^b - Pyroclastic rocks - Pliocene volcanic</p> <p><u>Susanville</u> qpv^b - Basalt - Pleistocene volcanic</p> <p><u>Chico</u> qv^b - Basalt - Pleistocene volcanic</p> <p><u>Santa Rosa</u> Qtcv - Dacite, andesite to basaltic rocks, basalt, rhyolite, tuff and other pyroclastic rocks - Clear Lake Volcanics</p>

Table 2

Scale: 1:750,000	Scale: 1:250,000
<p>Qv^P - Quaternary pyroclastic and volcanic mudflow deposits.</p> <p>Rating: ls - 2 df - 3 se - 3</p>	<p><u>Weed</u> Qv^P - Pyroclastic deposits - Volcanic rocks Qvs^P - Pyroclastic deposits - Volcanic rocks of Shasta Valley</p>
<p>QPc - Pliocene and/or Pleistocene sandstone, shale, and gravel deposits; mostly loosely consolidated.</p> <p>Rating: ls - 3 df - 2 se - 2</p>	<p><u>Weed</u> QT - Undifferentiated Plio-Pleistocene marine and non-marine deposits.</p> <p><u>Redding</u> Qc - Pleistocene nonmarine Puc - Upper Pliocene nonmarine</p> <p><u>Ukiah</u> QP - Plio-Pleistocene nonmarine Puc - Upper Pliocene nonmarine</p> <p><u>Alturas</u> Qc - Pleistocene nonmarine Pc - Undivided Pleistocene nonmarine</p> <p><u>Chico</u> Ps - Pliocene nonmarine sedimentary rocks (Fluvial and lacustrine shale, sandstone, and ash) Pl - Alluvial gravel, sand, and silt - Laguna Formation</p> <p><u>Santa Rosa</u> QT - Fluvial gravel, silt, sand, and clay (Includes undifferentiated continental deposits - Huichica and Glen Ellen Formations)</p> <p><u>San Francisco and San Jose</u> QT - Plio-Pleistocene nonmarine deposits (sand and gravel) Tg - "Auriferous" Gravels</p>
<p>P - Sandstone, siltstone, shale, and conglomerate; mostly moderately to well consolidated.</p> <p>Rating: ls - 2 df - 2 se - 2</p>	<p><u>Redding</u> Pu - Upper Pliocene marine QP - Plio-Pleistocene nonmarine Tm - Tertiary marine Mu - Upper Miocene marine Pml - Middle and/or lower Pliocene marine</p> <p><u>Santa Rosa</u> Pwg - Marine sandstone, conglomerate, and tuff - Wilson Grove Formation Qs - Dune and beach sand</p> <p><u>Santa Cruz</u> QP - Plio-Pleistocene nonmarine Pc - Undivided Pliocene nonmarine</p> <p><u>San Francisco and San Jose</u> Ppu - Marine sandstone and siltstone - Purisima Formation</p>

Table 2

Scale: 1:750,000	Scale: 1:250,000
<p>M - Sandstone, shale, siltstone, conglomerate, and breccia; moderately to well consolidated.</p> <p>Rating: ls - 3 df - 3 se - 2</p>	<p><u>Santa Rosa</u> Mgs - Marine sandstone and mudstone - Gallaway - Skooner Gulch Formations Mny - Marine sandstone and shale - Monterey Formation</p> <p><u>Santa Cruz</u> Mu - Upper Miocene marine Mm - Middle Miocene marine</p> <p><u>San Francisco and San Jose</u> Mmb - Basalt - Mindego Mny - Marine shale and sandstone - Monterey Formation Msm - Marine - Santa Margarita Sandstone Msc - Marine - Santa Cruz mudstone Mls - Marine - Lambert Shale</p>
<p>Tc - Undivided Tertiary sandstone, shale, conglomerate, breccia, and ancient lake deposits.</p> <p>Rating: ls - 2 df - 2 se - 2</p>	
<p>O - Sandstone, shale, conglomerate; mostly well consolidated.</p> <p>Rating: ls - 1 df - 2 se - 2</p>	<p><u>Santa Cruz</u> Oc - Oligocene marine</p> <p><u>San Francisco and San Jose</u> vq - Marine - Vaqueros Sandstone</p>
<p>Oc - Sandstone, shale, and conglomerate; mostly well consolidated.</p> <p>Rating: ls - 2 df - 3 se - 2</p>	<p><u>Redding</u> Oc - Oligocene nonmarine</p> <p><u>Alturas</u> Oc - Oligocene nonmarine</p>

Table 2

Scale: 1:750,000	Scale: 1:250,000
<p>Tv - Tertiary volcanic flow rocks; minor pyroclastic deposits.</p> <p>Rating: ls - 1 df - 1 se - 1</p>	<p><u>Weed</u> Pv^b - Basalt - Volcanic rocks Tv^a - Andesite with some basalt and dacite - Western Cascade Volcanics</p> <p><u>Redding</u> Pv^b - Basalt - Pliocene volcanic</p> <p><u>Ukiah</u> Tv^b - Basalt - Tertiary volcanic</p> <p><u>Alturas</u> Ti - Tertiary intrusive (hypabyssal) rocks Mv^b - Basalt - Miocene volcanic Pv^b - Basalt - Pliocene volcanic</p> <p><u>Susanyville</u> Pv^b - Basalt - Pliocene volcanic Tv^b - Basalt - Tertiary volcanic</p> <p><u>Chico</u> MPv^a - Andesite - Miocene-Pliocene volcanic rocks Pv^a - Andesite - Pliocene volcanic rocks MPv^t - Dacitic tuff-breccia - Miocene-Pliocene volcanic rocks Mlb - Basalt - Lovejoy</p> <p><u>Santa Rosa</u> Psv - Basalt, andesite, rhyolite, tuff and other pyroclastic rocks - Sonoma Volcanics</p> <p><u>San Francisco and San Jose</u> Mmb - Basalt - Mindego</p>

Table 2

Scale: 1:750,000	Scale: 1:250,000
<p>Tv^P - Tertiary pyroclastic and volcanic mudflow deposits.</p> <p>Rating: ls - 1 df - 1 se - 2</p>	<p><u>Weed</u> Tv^t - Rhyolite tuff - Western Cascade Volcanics Tv^P - Andesite tuff breccia - Western Cascade Volcanics</p> <p><u>Redding</u> Pv^P - Pyroclastic rocks - Pliocene volcanic</p> <p><u>Ukiah</u> Pv^P - Pyroclastic rocks - Pliocene volcanic</p> <p><u>Alturas</u> Tv^P - Pyroclastic rocks - Tertiary volcanic</p> <p><u>Susanville</u> Mv^P - Pyroclastic rocks - Miocene volcanic Tv^P - Pyroclastic rocks - Tertiary volcanic Ev^b - Basalt - Eocene volcanic Pv^P - Pyroclastic rocks - Pliocene volcanic</p> <p><u>Chico</u> MPv^{ap} - Andesite pyroclastic rocks - Miocene-Pliocene volcanic rocks</p> <p><u>Sacramento</u> Tm - Andesitic conglomerate, sandstone, and breccia - Mehrten Formation Tvs - Rhyolitic tuff and sedimentary rocks - Valley Springs Formation</p> <p><u>Mariposa</u> Pv^P - Pyroclastic rocks - Pliocene volcanic</p> <p><u>San Francisco and San Jose</u> Tm - Andesitic conglomerate - Mehrten Formation</p>
<p>Ti - Tertiary intrusive rocks; mostly shallow (hypabyssal) plugs and dykes.</p> <p>Rating: ls - 1 df - 1 se - 1</p>	<p><u>Chico</u> Mv - Oligocene-Miocene volcanic rocks</p>
<p>E - Shale, sandstone, conglomerate, limestone; mostly well consolidated.</p> <p>Rating: ls - 3 df - 3 se - 2</p>	<p><u>Santa Rosa</u> Pgr - Marine sandstone and mudstone - German Rancho Formation</p> <p><u>San Francisco and San Jose</u> Eum - Unnamed Eocene marine rocks Eb - Marine - Butano Sandstone E s - Marine mudstone - San Lorenzo Formation</p>
<p>Ep - Sandstone, shale, and conglomerate; mostly well consolidated.</p> <p>Rating: ls - 2 df - 2 se - 2</p>	<p><u>Redding</u> Ku - Upper Cretaceous marine.</p> <p><u>Santa Rosa</u> Pmz - Marine quartzose sandstone - Martinez Formation</p>

Table 2

Scale: 1:750,000	Scale: 1:250,000
<p>Ec - Sandstone, shale, conglomerate; moderately to well consolidated.</p> <p>Rating: ls - 2 df - 2 se - 2</p>	<p><u>Redding</u> Ku - Upper Cretaceous marine.</p> <p><u>Alturas</u> Ec - Eocene nonmarine.</p> <p><u>Chico</u> Tg - "Auriferous" Gravels t - Dredge or mine tailings</p>
<p>TK - Sandstone, shale, and minor conglomerate in coastal belt of northwestern California; included by some in Franciscan Complex. Previously considered Cretaceous, but now known to contain early Tertiary microfossils in places.</p> <p>Rating: ls - 2 df - 2 se - 2</p>	<p><u>Redding</u> K - Undivided Cretaceous marine.</p> <p><u>Ukiah</u> K - Undivided Cretaceous marine.</p> <p><u>Santa Rosa</u> TKf - Marine sandstone, shale, and conglomerate - Coastal Belt Franciscan</p>
<p>Ku - Upper Cretaceous sandstone, shale, and conglomerate.</p> <p>Rating: ls - 2 df - 2 se - 2</p>	<p><u>Weed</u> Kh - Marine; massive arkosic sandstone, conglomerate, and shale - Hornbrook Formation</p> <p><u>Redding</u> Ku - Upper Cretaceous marine</p> <p><u>Ukiah</u> Kl - Lower Cretaceous marine</p> <p><u>Susanville</u> Ku - Upper Cretaceous marine</p> <p><u>Chico</u> Kc - Sandstone, conglomerate, and siltstone; marine - Chico Formation</p> <p><u>Santa Rosa</u> Kga - Marine sandstone, mudstone, and conglomerate - Gyalala Formation</p> <p><u>Santa Cruz</u> Ku - Upper Cretaceous marine.</p>
<p>Kl - Lower Cretaceous sandstone, shale, and conglomerate.</p> <p>Rating: ls - 1 df - 2 se - 1</p>	<p><u>Redding</u> Kl - Lower Cretaceous marine.</p> <p><u>Ukiah</u> Ku - Upper Cretaceous marine Kl - Lower Cretaceous marine</p> <p><u>Santa Rosa</u> KJu - Lower Cretaceous-Upper Jurassic Great Valley Sequence (Marine mudstone, siltstone, sandstone, and conglomerate) Kl - Lower Cretaceous Great Valley Sequence (Marine mudstone, sandstone, and conglomerate)</p>
<p>J₁ - Shale, sandstone, minor conglomerate, chert, slate, limestone; minor pyroclastic rocks.</p> <p>Rating: ls - 2 df - 2 se - 2</p>	<p><u>Weed</u> Jg - Marine; slate, metagraywacke, and greenstone - Galice Formation</p> <p><u>Redding</u> Ju - Upper Jurassic marine Jml - Middle and/or Lower Jurassic marine ■ - Pre-Cretaceous metamorphic rocks</p>
<p>J₂ - Shale, sandstone, minor conglomerate, chert, slate, limestone; minor pyroclastic rocks.</p> <p>Rating: ls - 1 df - 1 se - 3</p>	<p><u>Redding</u> Jk - Knoxville Formation</p> <p><u>Ukiah</u> Jk - Knoxville Formation</p>

Table 2

Scale: 1:750,000	Scale: 1:250,000
<p>J₃ - Shale, sandstone, minor conglomerate, chert, slate, limestone; minor pyroclastic rocks.</p> <p>Rating: ls - 1 df - 1 se - 1</p>	<p><u>Weed</u></p> <p>Jp - Marine; argillite and tuffaceous sandstone - Potem Formation</p> <p>Ja - Volcaniclastic and pyroclastic rocks - Arvison Formation</p> <p>Jbg - Bagley Andesite.</p> <p><u>Redding</u></p> <p>Jml - Middle and/or Lower Jurassic marine</p> <p><u>Alturas</u></p> <p>Jml - Middle and/or Lower Jurassic marine</p> <p><u>Chico</u></p> <p>Jsc - Graywacke and slate; marine - Sailor Canyon Formation</p> <p>Jls - Limestone and marble - Sailor Canyon Formation</p> <p>Pzu - Paleozoic rocks of uncertain age and correlation (Quartzite, pelite, and conglomerate; marine)</p> <p><u>Sacramento</u></p> <p>Jls - Metasedimentary rocks - Sailor Canyon Formation</p> <p>Jm - Slate, graywacke, and conglomerate - Mariposa Formation</p> <p>ms - Metasedimentary rocks (horizontal line pattern denotes melange terrane)</p> <p><u>Mariposa</u></p> <p>- Jurassic-Triassic metavolcanic rocks.</p>
<p>KJF - Franciscan Complex: Cretaceous and Jurassic sandstone with smaller amounts of shale, chert, limestone, and conglomerate. Includes Franciscan mélangé, except where separated - see KJf_m.</p> <p>Rating: ls - 3 df - 2 se - 2</p>	<p><u>Weed</u></p> <p>KJfss - Sandstone, shale, conglomerate - Franciscan complex</p> <p>KJf - chert, greenstone and locally chert, metagraywacke, South Fork Mountain Schist, schist of Redwood Creek, blueschist blocks - Franciscan Formation</p> <p><u>Redding</u></p> <p>KJf - Franciscan Formation</p> <p><u>Ukiah</u></p> <p>KJf - Franciscan Formation</p> <p>ms - Pre-Cretaceous metasedimentary rocks</p> <p><u>Santa Rosa</u></p> <p>KJfss - Sandstone - Franciscan Complex</p> <p><u>San Francisco and San Jose</u></p> <p>KJf - Greenstone; sandstone, shale, conglomerate, metagraywacke, limestone, chert, serpentized ultramafic rock, blueschist blocks - Franciscan Complex</p> <p><u>Santa Cruz</u></p> <p>KJf - Franciscan Formation.</p>
<p>KJf_m - Mélangé of fragmented and sheared Franciscan Complex rocks.</p> <p>Rating: ls - 3 df - 2 se - 1</p>	<p><u>Weed</u></p> <p>KJfmg - Metagraywacke</p> <p>KJFum - Ultramafic rocks - partly to completely serpentized</p> <p><u>Santa Rosa</u></p> <p>KJf - Franciscan Formation</p> <p>KJfmg - Metagraywacke - Franciscan Formation</p>

Table 2

Scale: 1:750,000	Scale: 1:250,000
<p>KJf_s - Blueschist and semi-schist of Franciscan Complex</p> <p>Rating: ls - 3 df - 3 se - 2</p>	<p><u>Weed</u></p> <p>KJFrc - schist - schist of Redwood Creek</p> <p>KJFsfm - schist - South Fork Mountain Schist</p> <p><u>Redding</u></p> <p>KJfms - Pre-Cretaceous metasedimentary rocks</p> <p><u>Ukiah</u></p> <p>KJf - Franciscan Formation ms - Pre-Cretaceous metasedimentary rocks</p> <p><u>Santa Rosa</u></p> <p>KJfss - Sandstone - Franciscan Formation</p> <p><u>San Francisco and San Jose</u></p> <p>KJf - Greenstone; sandstone, shale, conglomerate, metagraywacke, limestone, chert, serpentinized ultramafic rock, blueschist blocks - Franciscan Complex</p>
<p>Mzv - Undivided Mesozoic volcanic and metavolcanic rocks. Andesite and rhyolite flow rocks, greenstone, volcanic breccia and other pyroclastic rocks; in part strongly metamorphosed. Includes volcanic rocks of Franciscan Complex: basaltic pillow lava, diabase, greenstone, and minor pyroclastic rocks.</p> <p>Rating: ls - 1 df - 1 se - 1</p>	<p><u>Weed</u></p> <p>Jv - Pillow lava and breccia - Volcanic rocks</p> <p>Jgd - Gabbro, diorite, and related rocks</p> <p>Jbg - Bagley Andesite</p> <p>Dc - Copley greenstone</p> <p><u>Redding</u></p> <p>v - Jura-Trias metavolcanic rocks</p> <p><u>Ukiah</u></p> <p>KJfv - Franciscan volcanic and metavolcanic rocks.</p> <p><u>Alturas</u></p> <p>v - Jurassic-Triassic metavolcanic rocks</p> <p><u>Chico</u></p> <p>Jm - Slate and sandstone; marine - Mariposa Formation</p> <p>Jmv - Metavolcanic rocks</p> <p>Jsc - Graywacke and slate; marine - Sailor Canyon Formation</p> <p>mv - Volcanic rocks - Smartville Formation</p> <p>Jv - Pyroclastic rocks and flows (Jurassic volcanic rocks) - Smartville Formation</p> <p>dc - Dike complex - Smartville Formation</p> <p><u>Santa Rosa</u></p> <p>sbp - Spilite near Black Point</p> <p>KJfgs - Greenstone - Franciscan Formation</p> <p>Jv - Volcanic rocks, mainly basalt</p> <p><u>Sacramento</u></p> <p>Jmv - Jurassic metavolcanic rocks</p> <p>Jlr - Logtown Ridge Formation</p> <p>mv - Metavolcanic rocks</p> <p><u>San Francisco and San Jose</u></p> <p>KJfgs - Greenstone - Franciscan Formation</p>

Table 2

Scale: 1:750,000	Scale: 1:250,000
<p>gr^{Mz} - Mesozoic granite, quartz monzonite, granodiorite, and quartz diorite.</p> <p>Rating: ls - 1 df - 3 se - 3</p>	<p><u>Weed</u> Mzg - Granitic rocks Mzd - Dioritic rocks Mzgb - Ultramafic-gabbroic rocks</p> <p><u>Redding</u> gr - Mesozoic granitic rocks</p> <p><u>Susanville</u> gr - Mesozoic granitic rocks</p> <p><u>Chico</u> KJqd - Quartz diorite, tonalite, trondhjemite, quartz monzonite KJgr - Granite, granodiorite Dbt - Trondhjemite, tonalite - Bowman Lake Batholith Dbg - Granite, granodiorite - Bowman Lake Batholith db - Massive diabase qd - Quartz diorite and tonalite Jdi - Diorite</p> <p><u>Santa Rosa</u> Kgr - Granitic rocks</p> <p><u>Sacramento</u> Mzd - Mesozoic dioritic rocks Mzg - Mesozoic granitic rocks</p> <p><u>Santa Cruz</u> gr - Mesozoic granitic rocks</p> <p><u>San Francisco and San Jose</u> Kgd - Cretaceous quartz diorite Mzg - Granitic rocks</p> <p><u>Fresno</u> gr - Mesozoic granitic rocks</p> <p><u>Mariposa</u> gr - Mesozoic granitic rocks</p>
<p>um₁ - Ultramafic rocks, mostly serpentine. Minor peridotite, gabbro, and diabase. Chiefly Mesozoic.</p> <p>Rating: ls - 3 df - 2 se - 1</p>	<p><u>Weed</u> Jum - Ultramafic rocks - partially to completely serpentinized</p> <p><u>Redding</u> ub - Mesozoic ultrabasic intrusive rocks</p> <p><u>Chico</u> Jum - Ultramafic rocks um - Ultramafic rocks Pzp - Peridotite of Melones fault zone (Partially to completely serpentinized)</p> <p><u>Santa Rosa</u> um - Serpentinized ultramafic rocks</p> <p><u>San Francisco and San Jose</u> um - Ultramafic rocks</p> <p><u>Mariposa</u> ub - Mesozoic ultrabasic intrusive rocks</p>
<p>um₂ - Ultramafic rocks, mostly serpentine. Minor peridotite, gabbro, and diabase. Chiefly Mesozoic.</p> <p>Rating: ls - 2 df - 2 se - 1</p>	<p><u>Weed</u> Op - Trinity peridotite (Partially serpentinized) MzPz-um - Serpentinite and metaserpentinite</p>

Table 2

Scale: 1:750,000	Scale: 1:250,000
<p>gb - Gabbro and dark dioritic rocks; chiefly Mesozoic.</p> <p>Rating: ls - 2 df - 2 se - 1</p>	<p><u>Weed</u> Ogb - Gabbroic and dioritic rocks (Minor pyroxenite) Mzd - Dioritic rocks Mzgb - Ultramafic-gabbroic rocks</p> <p><u>Chico</u> Jum - Ultramafic rocks gb - Gabbroic rocks db - Massive diabase</p> <p><u>Santa Rosa</u> Jgd - Gabbro and diabase</p> <p><u>Sacramento</u> gb - Gabbroic rocks</p> <p><u>San Francisco and San Jose</u> Mzgb - Gabbroic rocks</p>
<p>mv - Undivided pre-Cenozoic metavolcanic rocks. Includes latite, dacite, tuff, and greenstone; commonly schistose.</p> <p>Rating: ls - 3 df - 2 se - 2</p>	<p><u>Weed</u> MzPz-um - Serpentinite and metaserpentinite MzPz-sch - Amphibolite and greenschist</p> <p><u>Chico</u> Jmv - Metavolcanic rocks</p> <p><u>Sacramento</u> PzMz - Metamorphic rocks of unknown age (Quartz, mica, and hornblende schists)</p> <p><u>San Francisco and San Jose</u> Jms - Jurassic(?) metasedimentary rocks</p>
<p>gr-m - Granitic and metamorphic rocks, mostly gneiss and other metamorphic rocks injected by granitic rocks. Mesozoic to Precambrian.</p>	<p><u>Chico</u> MzPz-qd - Metadiorite</p> <p><u>Santa Cruz</u> m - Pre-Cretaceous metamorphic rocks</p>
<p>m - Undivided pre-Cenozoic metasedimentary and metavolcanic rocks of great variety. Mostly slate, quartzite, hornfels, chert, phyllite, mylonite, schist, gneiss, and minor marble.</p> <p>Rating: ls - 2 df - 2 se - 2</p>	<p><u>Weed</u> Sod - Marine; phyllite, graywacke, chert, and limestone - Duzel Formation Oam - Antelope Mountain Quartzite</p> <p><u>Chico</u> Jsc - Graywacke and slate; marine - Sailor Canyon Formation Jms - Metasedimentary rocks KJdi - Diorite mv - Volcanic rocks MzPz - Undifferentiated Paleozoic and Mesozoic rocks Jmo - Sandstone and slate; marine - Monte de Oro Formation mvs - Volcaniclastic sediments</p> <p><u>Sacramento</u> mv - Metavolcanic rocks</p> <p><u>Santa Cruz</u> m - Pre-Cretaceous metamorphic rocks</p> <p><u>Fresno</u> m - Pre-Cretaceous metamorphic rocks</p> <p><u>Mariposa</u> m - Pre-Cretaceous metamorphic rocks</p>
<p>sch₁ - Schists of various types; mostly Paleozoic or Mesozoic age; some Precambrian.</p> <p>Rating: ls - 3 df - 2 se - 2</p>	<p><u>Weed</u> Jcm - Condrey Mountain Schist</p>

Table 2

Scale: 1:750,000	Scale: 1:250,000
<p>sch₂ - Schists of various types; mostly Paleozoic or Mesozoic age; some Precambrian.</p> <p>Rating: ls - 1 df - 2 se - 1</p>	<p><u>Weed</u> Pza - Abrams Mica Schist (Grouse Ridge Formation) Pzs - Salmon Hornblende Schist</p> <p><u>Redding</u> pSs - Pre-Silurian metasedimentary rocks</p>
<p>ls - Limestone, solomite, and marble whose age is uncertain but probably Paleozoic or Mesozoic.</p> <p>Rating: ls - 1 df - 1 se - 1</p>	<p><u>Sacramento</u> ls - Crystalline limestone and dolomite</p>
<p>- Shale, conglomerate, limestone and dolomite, sandstone, slate, hornfels, quartzite; minor pyroclastic rocks.</p> <p>Rating: ls - 1 df - 1 se - 1</p>	<p><u>Weed</u> md - Andesitic volcanoclastic and pyroclastic rocks - Modin Formation p - Marine; shale and siltstone (includes Brock Shale and Hosselkus Limestone) - Pit Formation</p> <p><u>Redding</u> - Triassic marine</p> <p><u>Chico</u> s - Slate, conglomerate, and greenstone (marine) - Permian and Triassic rocks</p>
<p>Pm - Shale, conglomerate, limestone and dolomite, sandstone, slate, hornfels, quartzite; minor pyroclastic rocks.</p> <p>Rating: ls - 1 df - 2 se - 1</p>	<p><u>Weed</u> ml - McCloud limestone</p>
<p>C - Shale, sandstone, conglomerate, limestone, dolomite, chert, hornfels, marble, quartzite in part pyroclastic rocks.</p> <p>Rating: ls - 1 df - 2 se - 1</p>	<p><u>Weed</u> Cbg - Marine; shale, graywacke, and minor conglomerate - Bragdon Formation Cb - Pyroclastic rocks and keratophyre - Baird Formation</p> <p><u>Redding</u> CM - Mississippian marine</p>
<p>D - Limestone and dolomite, sandstone and shale; in part tuffaceous.</p> <p>Rating: ls - 1 df - 2 se - 1</p>	<p><u>Weed</u> Dsg - Marine; sandstone, shale, chert, conglomerate, and limestone - Gazelle Formation Dkn - Marine; siliceous shale and tuff - Kennett Formation</p>
<p>SO - Sandstone, shale, conglomerate, chert, slate, quartzite, hornfels, marble, dolomite, phyllite; some greenstone.</p> <p>Rating: ls - 1 df - 1 se - 1</p>	<p><u>Weed</u> Sinc - Sheared sandstone and shale - Moffett Creek Formation</p>

Table 2

Scale: 1:750,000	Scale: 1:250,000
<p>Pz₁ - Undivided Paleozoic metasedimentary rocks. Includes slate, sandstone, shale, chert, conglomerate, limestone, dolomite, marble, phyllite, schist hornfels, and quartzite.</p> <p>Rating: ls - 2 df - 1 se - 1</p> <p>-----</p> <p>Pz₂ - Undivided Paleozoic metasedimentary rocks. Includes slate, sandstone, shale, chert, conglomerate, limestone, dolomite, marble, phyllite, schist hornfels, and quartzite.</p> <p>Rating: ls - 3 df - 2 se - 2</p>	<p><u>Weed</u></p> <p>MzPz-sch - Amphibolite and greenschist MzPz-ms - Metasedimentary rocks MzPz-rct - Rattlesnake Creek terrane MzPz-hft - Hayfork terrane MzPz-nft - North Fork terrane MzPz-mvs - Metavolcaniclastic sedimentary rocks MzPz-gb - Gabbro</p> <p><u>Redding</u></p> <p>m - Pre-Cretaceous metamorphic rocks</p> <p><u>Chico</u></p> <p>Cp - Bedded chert, shale, pillow lavas, and tuff - Peale Formation r - Andesitic breccia, flows, and tuff - Reeve Formation Pzsf - Shoo Fly Complex MzPz - Undifferentiated Paleozoic and Mesozoic rocks Pza - Paleozoic amphibolite Pzcc - Chert and argillite - Calaveras Formation</p> <p><u>Sacramento</u></p> <p>Pzu7 - Undifferentiated Paleozoic(?) rocks ms - Metasedimentary rocks</p> <p><u>Mariposa</u></p> <p>- Paleozoic marine</p> <p><u>San Francisco and San Jose</u></p> <p>Pzcc - Metasedimentary rocks - Calaveras Formation Pzsf - Metasedimentary rocks - Shoo Fly Complex</p>
<p>p c - Complex of Precambrian igneous and metamorphic rocks. Mostly gneiss and schist intruded by igneous rocks; may be Mesozoic in part.</p>	
<p>Pzv - Undivided Paleozoic metavolcanic rocks. Mostly flows, breccia, and tuff, including greenstone, diabase and pillow lavas; minor interbedded sedimentary rocks.</p> <p>Rating: ls - 2 df - 2 se - 1</p>	<p><u>Weed</u></p> <p>Pm - Bollibokka Group - Dekkas and Mosoni Formations, undifferentiated) Trb - Andesite, medsonite, and tuff) - Bollibokka Group Dc - Copley Greenstone</p> <p><u>Redding</u></p> <p>Dv - Devonian metavolcanic rocks Pmv - Permian metavolcanic rocks</p> <p><u>Alturas</u></p> <p>TR - Triassic marine</p> <p><u>Chico</u></p> <p>CDt - Andesitic breccia, tuff, and slate - Taylor Formation Dsb - Rhyolitic to andesitic flows, breccia, tuffs, and chert - Sierra Buttes Formation MzPz-mv - Metavolcanic rocks MzPz-ms - Metasedimentary rocks Jgb - Gabbro</p> <p><u>Sacramento</u></p> <p>Pzcv - Volcanic rocks - Calaveras Formation</p>

Table 3

DATA INPUT

Slope	Rating	
	Debris Slide/Surface Erosion	Landslide
0-1%	0	0
10-30%	1	1
30-50%	2	3
>50%	3	2
Precipitation		
Two-Hour Storm		
inches/hour		
0-0.6	1	
0.6-1.2	2	
>1.2	3	
Twelve-Hour Storm		
inches/hour		
0-0.2	1	
0.2-0.4	2	
>0.4	3	
Mean Annual		
inches/hour		
0-40	1	
40-60	2	
>60	3	

Relative Ratings of Erosion Potential

WATERSHED	TOTAL	LANDSLIDE	DEBRIS SLIDE	SURFACE EROSION
NUMBER	RELATIVE	RELATIVE	RELATIVE	RELATIVE
	RATING	RATING	RATING	RATING
101001	5	6	5	4
102301	6	7	5	4
103111	2	2	2	2
103121	5	7	5	4
103131	4	5	4	3
103205	5	6	6	5
103501	5	6	5	4
105111	6	7	6	4
105112	6	7	6	5
105113	6	7	6	5
105114	5	6	5	4
105116	6	7	6	5
105117	5	6	5	4
105118	5	6	5	4
105331	5	6	5	4
105351	4	4	4	4
105352	4	4	4	3
105353	4	5	4	4
105354	4	5	4	3
105355	4	5	4	3
105362	2	3	2	2
105363	3	3	3	3
105371	2	2	2	2
105381	2	2	2	2
105411	5	6	5	5
105413	5	5	5	4
105420	4	5	4	4
105421	4	4	4	3
105422	4	4	4	4
105423	5	4	5	5
105424	4	3	4	4
105425	4	3	4	4
105426	4	3	4	3
105427	3	3	3	3
105428	4	4	4	3
105429	4	5	4	4
105501	3	3	3	3
105502	3	3	3	3
105504	3	3	3	3
105506	3	3	3	2
105508	2	2	2	2
105509	2	2	2	2
105811	2	2	2	2
105821	1	1	1	1
105822	1	1	1	1
105823	3	3	3	2
105831	2	3	3	2
106113	5	6	6	4

Table 4 (continued)

WATERSHED	TOTAL	LANDSLIDE	DEBRIS SLIDE	SURFACE EROSION
NUMBER	RELATIVE	RELATIVE	RELATIVE	RELATIVE
	RATING	RATING	RATING	RATING
106121	5	6	5	5
106122	5	5	5	4
106135	5	5	5	5
106157	4	5	4	3
106212	6	7	5	5
106213	5	6	5	5
106214	6	6	5	5
106221	5	5	5	4
106234	3	4	3	3
106237	5	6	5	4
106242	4	4	4	4
106252	4	4	4	4
106311	4	5	4	4
106312	4	4	4	3
106313	5	5	5	4
106314	4	5	5	4
106316	4	4	5	4
106317	4	4	4	4
106325	3	3	4	3
106400	4	4	4	3
106401	5	5	6	4
106402	5	5	6	5
106403	5	5	5	3
106404	5	6	6	4
106406	5	5	6	5
106407	4	4	4	4
107106	3	3	3	2
107201	6	7	5	5
107202	6	7	6	5
107203	6	7	6	4
107204	6	7	6	5
107301	5	7	5	4
107302	5	6	5	4
108101	3	4	3	3
108201	3	4	3	3
109101	2	2	2	2
109201	5	6	4	4
109303	5	7	4	4
109304	5	7	5	5
109305	5	6	4	4
109306	4	5	4	4
109402	5	6	4	4
110001	3	4	3	3
110002	3	3	3	3
110003	3	3	3	3
110004	1	1	1	1
110005	1	1	1	1
111111	4	5	4	4
111112	2	2	2	2
111113	1	2	1	1
111121	4	4	4	4

Table 4 (continued)

WATERSHED	TOTAL	LANDSLIDE	DEBRIS SLIDE	SURFACE EROSION
NUMBER	RELATIVE	RELATIVE	RELATIVE	RELATIVE
	RATING	RATING	RATING	RATING
111122	5	5	4	4
111131	5	6	5	4
111132	5	6	5	4
111133	5	6	5	4
111211	3	3	3	3
111220	5	5	5	4
111222	5	6	4	4
111223	5	6	4	4
111224	5	6	4	4
111225	5	6	5	4
111231	5	5	4	4
111311	5	5	5	4
111312	5	6	5	4
111313	5	6	5	4
111321	5	6	5	4
111322	5	6	5	4
111323	4	5	4	4
111324	5	6	5	4
111325	4	5	5	4
111326	5	6	5	4
111327	4	5	5	4
111328	4	5	5	4
111331	3	3	3	2
111332	4	5	4	3
111333	4	5	4	4
111334	5	6	5	4
111411	5	5	5	4
111412	5	6	5	4
111413	5	6	5	4
111414	5	6	5	4
111415	6	7	5	5
111416	5	5	5	4
111421	5	5	5	4
111422	5	6	6	5
111423	5	6	5	4
111424	5	6	6	5
111425	5	5	5	4
111426	5	6	5	4
111501	4	5	4	4
111504	4	5	5	4
111611	2	3	3	2
111612	3	3	3	3
111613	4	4	4	3
111621	5	5	5	4
111622	4	5	4	4
111624	5	5	5	4
111631	5	6	6	4
111635	4	4	3	3
111638	5	5	5	4
111639	5	5	5	4
111713	5	6	5	4

Table 4 (continued)

WATERSHED	TOTAL	LANDSLIDE	DEBRIS SLIDE	SURFACE EROSION
NUMBER	RELATIVE	RELATIVE	RELATIVE	RELATIVE
	RATING	RATING	RATING	RATING
111714	4	5	5	4
111721	5	6	5	5
111722	4	4	4	3
111723	4	4	4	3
111724	1	1	1	1
111725	3	3	3	3
111734	5	6	5	5
112201	5	6	5	5
112202	5	5	4	4
112301	4	4	4	3
112303	5	5	5	4
112304	5	6	5	5
112305	5	5	4	4
112306	5	6	5	5
112307	4	4	4	4
113111	5	5	5	4
113112	5	5	5	4
113121	5	5	5	4
113122	5	5	5	5
113131	5	6	5	5
113132	5	5	5	4
113133	4	4	5	4
113134	4	4	5	4
113201	5	5	5	4
113203	4	4	4	3
113204	1	1	1	1
113205	2	2	2	2
113301	5	5	5	4
113302	5	6	5	4
113303	5	5	5	4
113304	3	3	3	3
113401	3	3	3	3
113500	4	4	5	4
113502	4	4	5	4
113503	4	3	4	3
113504	4	5	5	4
113505	5	5	5	4
113506	4	4	4	4
113507	4	4	4	3
113611	4	4	4	4
113631	4	5	4	4
113641	4	4	4	3
113701	5	5	5	4
113702	4	4	4	3
113703	2	2	3	2
113811	5	5	5	4
113831	4	5	5	4
113841	5	5	5	4
113842	4	5	4	3
113843	4	4	4	3
113850	3	4	4	3

Table 4 (continued)

WATERSHED	TOTAL	LANDSLIDE	DEBRIS SLIDE	SURFACE EROSION
NUMBER	RELATIVE	RELATIVE	RELATIVE	RELATIVE
	RATING	RATING	RATING	RATING
113851	3	4	4	3
113852	2	2	3	2
113853	3	2	3	3
113901	4	4	4	3
114111	1	1	2	1
114113	4	4	4	3
114114	4	4	4	3
114121	5	5	5	3
114221	2	2	2	2
114241	4	4	4	4
114242	4	4	5	4
114243	3	3	3	2
114244	5	5	5	4
114245	4	4	5	4
114251	3	3	4	3
114253	2	2	2	2
114255	2	2	3	2
114261	5	6	5	4
114262	4	5	5	4
114310	3	4	3	3
114311	4	4	4	4
114313	4	4	4	3
114320	3	4	3	3
114330	4	4	4	3
115100	2	3	3	2
115201	1	1	1	1
115301	1	1	2	1
201121	3	3	3	3
201122	3	3	3	2
201123	2	2	2	1
201131	3	3	4	3
201132	4	4	4	3
201133	3	3	3	3
206402	2	2	2	2
206502	2	2	3	3
206503	3	3	4	3
206504	4	4	4	3
206505	3	2	3	2
505101	4	5	5	4
505105	4	5	5	4
505210	5	6	6	4
505211	5	5	5	4
505212	5	6	6	4
505221	2	2	2	2
505231	3	3	3	2
505241	2	2	2	1
505242	1	1	1	1
505243	1	1	1	1
525244	2	2	2	2
505246	2	2	2	2
505247	2	2	1	1

Table 4 (continued)

WATERSHED	TOTAL	LANDSLIDE	DEBRIS SLIDE	SURFACE EROSION
NUMBER	RELATIVE	RELATIVE	RELATIVE	RELATIVE
	RATING	RATING	RATING	RATING
506100	4	4	4	4
506201	5	6	6	5
506203	3	3	4	3
506204	5	6	6	5
506205	4	4	4	4
506206	4	4	4	3
507121	2	2	2	2
507123	1	1	1	1
507124	2	2	2	2
507125	3	3	3	3
507126	2	2	3	2
507220	1	1	1	1
507221	1	1	1	1
507222	3	3	3	3
507223	1	1	1	1
507224	1	1	1	1
507311	2	2	2	2
507321	2	2	2	2
507322	1	1	1	1
507331	2	2	2	2
507332	2	2	2	2
509141	3	4	3	3
509142	4	4	4	4
509150	2	2	2	2
509161	3	3	3	3
509162	3	2	3	3
509201	3	3	3	2
509203	3	3	3	3
509631	2	2	3	3
509632	2	2	3	2
509640	1	1	1	2
509641	2	2	2	2
512301	4	4	4	3
513403	4	4	4	3
513541	4	5	5	4
513551	3	3	3	3
513552	2	2	3	2
514311	2	2	2	3
514321	3	3	3	3
514322	3	3	3	3
514323	2	2	2	2
514324	2	2	2	2
514325	2	2	2	2
514326	2	1	2	2
514332	2	3	2	2
514333	3	4	3	3
514334	2	2	2	2
514342	3	3	3	3
514343	2	2	2	2
514352	4	4	5	5
514353	3	3	3	3

Table 4 (continued)

WATERSHED	TOTAL	LANDSLIDE	DEBRIS SLIDE	SURFACE EROSION
NUMBER	RELATIVE	RELATIVE	RELATIVE	RELATIVE
	RATING	RATING	RATING	RATING
514354	4	3	4	4
514363	4	3	4	4
214412	3	3	3	3
514413	2	2	2	2
514414	3	3	3	3
514433	4	4	5	4
514434	3	2	3	3
514441	2	2	3	2
514442	3	3	3	3
514511	2	2	2	2
514521	3	3	3	2
514531	4	4	4	3
514541	4	4	4	3
514551	4	4	4	4
516321	1	1	1	1
516322	1	1	1	1
516330	2	2	2	1
516331	1	1	1	1
516341	4	5	4	3
516342	3	4	3	3
516343	2	2	2	2
517131	2	2	2	2
517132	2	2	2	2
517133	2	1	2	2
517141	3	2	3	3
517201	2	2	2	2
517202	1	1	2	1
517311	2	2	3	2
517321	4	4	4	3
517322	4	5	4	4
517323	3	3	3	3
517331	4	4	4	3
517341	3	3	3	3
517342	3	3	3	3
517343	4	4	4	4
517411	3	3	3	3
517412	3	3	3	3
517421	4	5	4	4
517431	3	3	3	3
517511	3	3	3	2
517512	3	3	4	3
517542	4	5	4	4
517601	2	2	3	3
518110	4	3	5	4
518112	4	4	4	3
518113	3	3	4	3
518114	4	3	4	4
518115	3	3	3	3
518116	2	2	2	2
518121	1	1	1	1
518221	4	4	4	4

Table 4 (continued)

WATERSHED	TOTAL	LANDSLIDE	DEBRIS SLIDE	SURFACE EROSION
NUMBER	RELATIVE	RELATIVE	RELATIVE	RELATIVE
	RATING	RATING	RATING	RATING
518222	3	3	4	3
518231	3	3	3	3
518324	3	3	3	3
518326	3	3	4	3
518330	3	3	3	3
518331	2	1	2	2
518332	3	3	3	3
518333	3	3	3	3
518334	3	3	4	3
518335	3	3	4	4
518355	3	3	3	3
518410	1	1	1	1
518423	4	4	5	4
518424	5	5	5	4
518425	4	4	5	4
518430	1	1	1	1
518432	3	3	3	3
518434	2	2	3	2
518443	2	2	2	2
518444	2	2	2	1
518445	1	1	1	1
518446	1	1	1	1
518447	2	2	2	2
518448	1	1	1	1
518452	1	1	1	1
518453	2	1	2	2
518454	1	1	2	1
518455	2	2	3	2
518456	3	3	3	2
518457	0	0	0	0
518511	4	4	4	3
518512	4	4	4	3
518522	3	3	4	3
518523	3	3	4	3
518532	3	3	3	4
518534	3	3	4	3
518535	3	3	3	3
518600	6	7	6	5
518601	3	3	3	3
518602	4	4	4	3
518604	3	3	3	3
520212	1	1	1	1
520400	1	1	1	1
521100	1	1	1	2
521200	3	2	3	3
521303	3	3	3	3
522242	4	4	4	3
523102	6	6	6	5
523103	5	6	6	5
523211	5	5	5	4
523212	3	3	4	3

Table 4 (continued)

Relative Ratings of Erosion Potential

WATERSHED	TOTAL	LANDSLIDE	DEBRIS SLIDE	SURFACE EROSION
NUMBER	RELATIVE	RELATIVE	RELATIVE	RELATIVE
	RATING	RATING	RATING	RATING
534225	2	2	3	2
534301	3	2	3	3
534303	2	2	3	2
534411	4	4	4	4
534412	4	4	4	4
534413	3	3	4	3
534416	2	2	3	2
534501	3	3	4	3
534502	3	3	3	3
534503	3	3	4	4
534504	3	3	3	3
534505	5	4	6	5
536314	4	3	4	4
536401	1	1	1	1
536402	4	3	4	4
536516	4	3	4	3
536603	3	3	4	3
540304	3	2	3	3
540405	3	3	4	4
603206	2	2	2	2
603208	3	2	3	3
630301	2	2	2	2
630303	2	2	2	1
630307	2	2	2	2
630401	3	2	3	2
630403	3	3	4	3
631403	2	2	2	2
631406	3	2	4	3
633201	3	3	4	3
634103	3	2	4	3
635202	3	3	3	3
635204	2	2	2	1
635205	2	2	3	2
636001	3	3	3	2
637201	1	1	1	1
637202	1	1	1	1
637203	1	1	2	1
637205	2	2	2	2
637206	2	2	2	2
637207	2	1	2	2
637208	2	2	2	2
637209	3	2	3	3
637316	2	2	2	1
637401	2	2	3	2

For slope, precipitation, and geologic material strength, values of low, moderate, and high (corresponding to 1, 2, and 3 consecutively) were assigned to each pixel. These pixels were summed and averaged for each data layer within a watershed. The data layer ratings were then added and averaged to calculate an erosion rating for each watershed. The results of these three erosion ratings were then added to estimate the total erosion potential for each watershed.

Table 5

FIELD/OBSERVATIONS OF ERODIBLE WATERSHEDS

Map #	Watershed #	Reference	Agency	Comments
1	105353	Inventory Questionnaire	CDF	
2	105363	Inventory Questionnaire	CDF	
3	105352	Inventory Questionnaire	WQC	Hungry Creek
4	105331	Inventory Questionnaire	CDF	
5	105354	Inventory Questionnaire	CDF	
6	105351	Inventory Questionnaire	WQC	Dutch Creek
7	305509	Inventory Questionnaire	CDF	
8	105427	Inventory Questionnaire		
9	105424	Sommarstrom et al, 1990	WQC	Kidder Creek
10	105422	Inventory Questionnaire	CDF	
11	105421	Inventory Questionnaire		
12	105423	Sommarstrom et al, 1990	WQC	Several watersheds mentioned.
13	103206	Inventory Questionnaire		
14	103131	Inventory Questionnaire		
15	103501	Inventory Questionnaire		
16	105118	Inventory Questionnaire		
17	105117	Inventory Questionnaire	DF&G	
18	107105	Janda et al, 1975 Nolan and Janda, 1981		
19	107204	Janda et al, 1975		
20	108201	Janda et al, 1975 Kilbourne, R., 1985b		
21	107203	Janda et al, 1975 Kilbourne, R., 1985b		
22	107202	Janda et al, 1975 Kilbourne, R., 1985b	CDF	
23	109101	Brown, 1975 Kilbourne, R., 1985a Kilbourne, R., 1985b Inventory Questionnaire		
24	109201	Kilbourne, R., 1985a		
25	107201	Janda et al, 1975 Inventory Questionnaire		
26	110001	Kilbourne, R., 1985b		
27	109306	Brown, 1975 Inventory Questionnaire		
28	107302	Janda et al, 1975 Inventory Questionnaire		
29	109305	Brown, 1975 Inventory Questionnaire	DF&G	

Table 5 (continued)

Map #	Watershed #	Reference	Agency	Comments
30	107301	Janda et al, 1975 Inventory Questionnaire	DF&G	
31	109304	Brown, 1975 Inventory Questionnaire	DF&G	
32	106212	Scott et al, 1979 Inventory Questionnaire	DF&G	
33	109303	Brown, 1975 Inventory Questionnaire	DF&G	
34	106221	Scott et al, 1979 Inventory Questionnaire		
36	109301	Brown, 1975	DF&G	
37	106237	Scott et al, 1979		
38	111223	Kelsey, 1979 Inventory Questionnaire	DF&G	
39	111220	Kelsey, 1979 Inventory Questionnaire Spittler, T.E., 1983c	DMG	
40	111122	Spittler, T.E., 1982a Spittler, T.E., 1982b Inventory Questionnaire	DMG DMG	
41	111313	Spittler, T.E., 1983a Spittler, T.E., 1983b Inventory Questionnaire	DMG DMG	
42	109403	Brown, 1975		
43	106235	Scott et al, 1979		
44	109402	Brown, 1975		
45	106233	Scott et al, 1979		
46	106232	Scott et al, 1979		
47	106231	Scott et al, 1979		
48	109401	Brown, 1975		
49	?	Inventory Questionnaire	DMG	Grass Valley Creek. Little private ownership
50	106314	Inventory Questionnaire		
51	106316	U.S. Dept. of Agriculture, Soil Conservation Service, 1986 Inventory Questionnaire	WQC	Browns Creek
52	106311	Inventory Questionnaire	DMG	DG soil.
53	106313	Inventory Questionnaire	WQC	Indian Creek
54	524351	Inventory Questionnaire		
55	524352	Inventory Questionnaire	DMG	DG
56	524621	Inventory Questionnaire		
57	111502	Inventory Questionnaire		
58	111503	Inventory Questionnaire		
59	111501	Inventory Questionnaire	DF&G	
60	111326	Inventory Questionnaire		

Table 5 (continued)

Map #	Watershed #	Reference	Agency	Comments
61	111324	Inventory Questionnaire		
62	523101	Inventory Questionnaire	DMG	Thomes Creek
63	523102	Inventory Questionnaire	DMG	Thomes Creek
64	523103	Inventory Questionnaire		
65	523212	Inventory Questionnaire		
66	111713	Inventory Questionnaire		
67	111732	Inventory Questionnaire		
68	111712	Inventory Questionnaire	DF&G	
69	111711	Inventory Questionnaire	DF&G	
70	113631	Inventory Questionnaire		
71	113641	Inventory Questionnaire		
72	113702	Inventory Questionnaire		
73	113701	Inventory Questionnaire	DF&G	
74	113831	Inventory Questionnaire		
75	114242	Larson and Sidle, 1980		
76	113843	Inventory Questionnaire		
77	114262	Larson and Sidle, 1980 Bedrossian, 1980		
78	114261	Larson and Sidle, 1980 Bedrossian, 1980		
79	526144	Inventory Questionnaire	DMG	Western 1/2 watershed is landslide terrane.
80	526143	Inventory Questionnaire		
81	526142	Inventory Questionnaire		
82	526141	Inventory Questionnaire	DMG	Western 1/2 watershed is landslide terrane.
83	526332	Inventory Questionnaire		
84	507332	Inventory Questionnaire	DMG	40% landslide terrane.
85	507331	Inventory Questionnaire	DMG	60-70% landslide terrane.
86	507322	Inventory Questionnaire		
87	507311	Inventory Questionnaire		
88	507222	Inventory Questionnaire		
89	507223	Inventory Questionnaire		
90	507224	Inventory Questionnaire		
91	637316	Inventory Questionnaire		
92	637206	Inventory Questionnaire		
93	637208	Inventory Questionnaire		
94	637209	Inventory Questionnaire	CDF	DG, Honey Lake escarpment.
95	518535	Inventory Questionnaire	CDF	Streams carrying excessive amt. of sediment.
96	518534	Inventory Questionnaire		